AD-A035 334 ARMY AVIATION SYSTEMS COMMAND ST LOUIS MO F/G 1/3
ARMY AVIATION RDT AND E PLAN.(U)
OCT 76

UNCLASSIFIED NL

1 OF 4
AD
A035334

OF 4

5334

①

ARMY AVIATION RDT & E PLAN

OCTOBER 1976

(6) # ARMY AVIATION RDT&E PLAN. and OK

[redacted]

(11) OCTOBER 1976

UNCLASSIFIED VOLUME

(12) 262p.

(9) Edition No. 5.

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

ADDITIONAL COPIES OF THE EXECUTIVE SUMMARY
OR OF THE RDT&E PLAN
MAY BE OBTAINED FROM:

DIRECTOR
U.S. ARMY AIR MOBILITY R&D LABORATORY
AMES RESEARCH CENTER
MOFFETT FIELD, CA 94035

U.S. ARMY AVIATION SYSTEMS COMMAND
ST. LOUIS, MISSOURI

404 318
bpg

FOREWORD

The Army Aviation Research, Development, Test and Engineering (RDT&E) Plan is the U.S. Army Aviation Systems Command (USAAVSCOM) response to the requirement for a Consolidated R&D Plan, which constitutes Block 13a in the Life-Cycle Management Model as described in the Joint CDC/AMC Materiel Need Procedures Handbook, March 1972. This Plan is prepared and maintained by AVSCOM on a continuing basis to address the short- and long-range RDT&E activities directed to achieving the Army objectives for which AVSCOM is responsible.

This Plan presents a time-phased analysis and presentation of the scientific and technological programs required to support the development of advanced airmobile systems responsive to the future needs of the Army. This document sets forth plans and objectives for Army aviation research and development activities for the FY77–96 period, with particular emphasis on the period from the present to 1981. Current R&D efforts in Army air mobility are directed primarily toward the development of a family of vertical and short takeoff and landing aircraft to fulfill identified requirements in the land combat functions of mobility, intelligence, firepower, combat service support, and command, control, and communications.

This is the fifth issue of a document that will continue to be reviewed, revised, and augmented annually. The 1976 publication (FY77 Plan) has been printed in one basic volume. A classified annex containing CONFIDENTIAL material on a variety of subjects and including projected Initial Operational Capability dates has been published to supplement the basic unclassified Plan. The Plan has been realigned in the Airmobile Systems section to present the operational systems, developing systems, and R&D planning concepts as an element of the land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication rather than individual sections for individual systems. The discussions on program planning, in the technology section, include the philosophy of AVSCOM's Project Selection Process with the development of technical thrusts for the individual technologies. The Plan covers RDT&E activities (6.1 through 6.7 program categories) and also MM&T activities, which are normally part of Procurement of Equipment and Missiles-Army (PEMA).

EIVIND H. JOHANSEN
Major General, USA
Commanding

TABLE OF CONTENTS

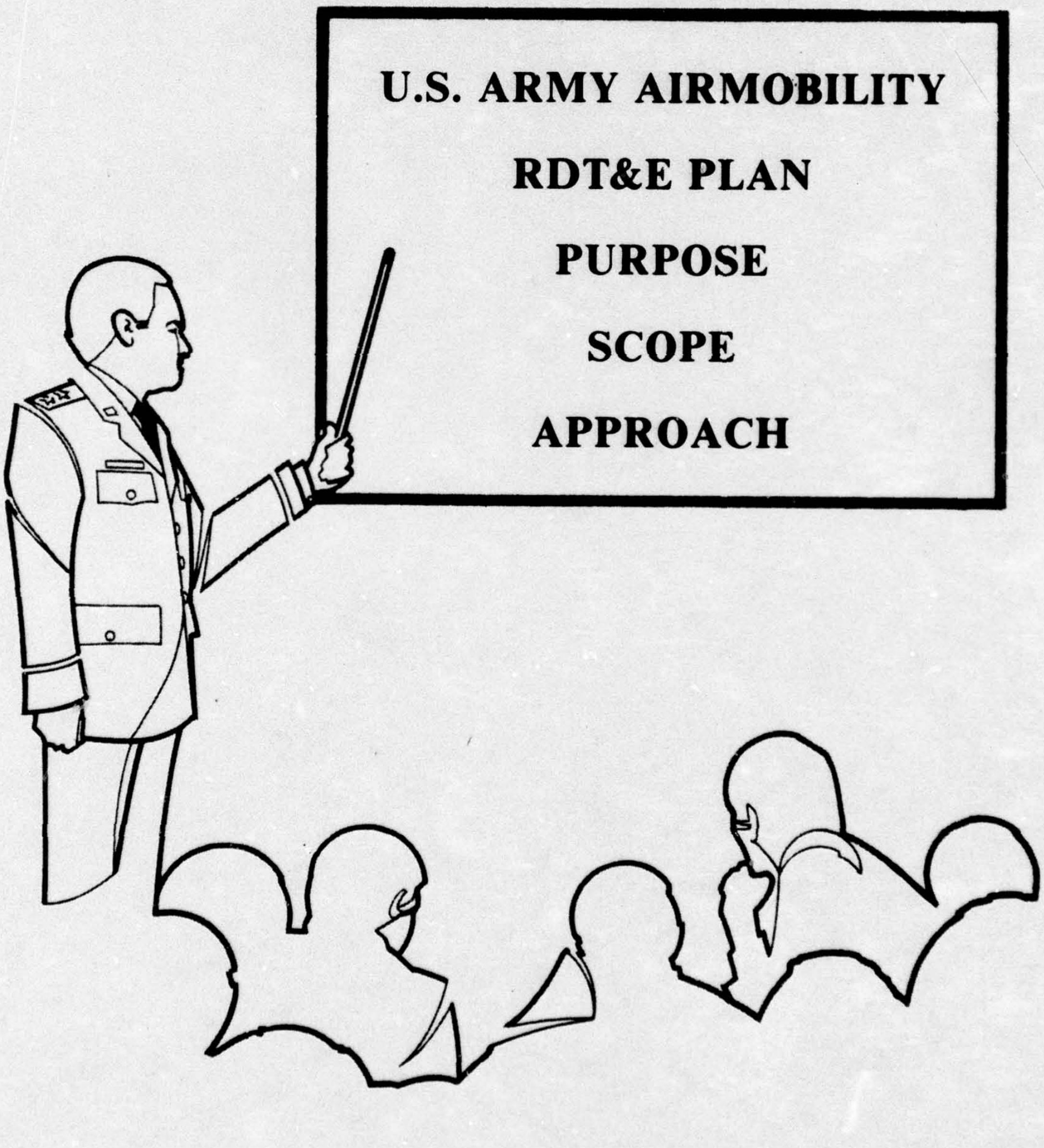
S to p. vi

to p. vii

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF CHARTS


U.S. ARMY AIRMOBILITY
RDT&E PLAN
PURPOSE
SCOPE
APPROACH

PURPOSE

The Army Aviation RDT&E Plan is prepared by the U.S. Army Aviation Systems Command as its response to the requirement for a Consolidated R&D Plan described in the Joint CDC/AMC Materiel Need Procedures Handbook, March 1972.

Superiority of future Army airmobile systems depends on the availability and exploitation of new scientific knowledge, the existence of which can only be estimated. The development of a firm technology base to meet projected requirements can be assured by formulating a time-phased prediction of technical potential set forth in an orderly sequence of coordinated activities in the many disciplines and technologies required to develop airmobile systems. An objective of the Army Aviation RDT&E Plan is to provide such an evaluation of technical potential. The Plan presents an instantaneous assessment, and therefore requires continual review and updating to account for technological advances or changes in threat or policy for requirements.

The primary concepts emphasized during the preparation of this Plan are:

- The establishment of substantial research and exploratory development efforts directed toward the long term satisfaction of technological deficiencies; vitalization of the technology base; pursuit of aggressive policies, with innovation as appropriate, for stimulation of the productivity of the technology base.
- The initiation and continuation of specific prototypes, advanced technology demonstrators and new initiatives to exploit promising new concepts and technology potentially capable of substantial impact in areas of significant force deficiency.
- The continued development, test, and evaluation of major systems with a substantial effort to orient programs for their development toward achievement of more realistic production, operational, and maintenance costs.

The Plan seeks to explore all viable options for future systems, with the goal of providing knowledgeable elimination of options and identification of optimum concepts for development when required. The more distant the operational date, the more options are pursued, and at the more fundamental research level.

The Plan is intended as a management tool to provide visibility of acknowledged requirements and interdependence of necessary technological achievements. While the Plan establishes the basis for programming, it is not in itself a program. It is not constrained by available resources, but is the foundation on which a program can be structured within such constraints.

The Plan is dedicated to development of the best combat vehicles possible for the defense of this country. However, the planned developmental activities are continually cognizant of the need to minimize any environmental degradation that might occur because of operation of these new systems. Great emphasis is placed on the reduction of noise and atmospheric pollution.

SCOPE

The Plan sets forth plans and objectives for Army aviation R&D activities for FY77 through 96, with particular emphasis on FY77 through 81.

The Plan addresses, and is in harmony with, the following documents:

- DA objectives, policies, and guidance for RDT&E including:
  - The Army Program Objectives Memorandum (POM).
  - The Army Strategic Objectives Plan (ASOP).
  - The Army Force Development Plan (AFDP).
  - The Army R&D Planning System (ARDPS), including the Threat Estimates, Army System Coordinating Documents (ASCODs), the Research and Technology Coordinating Document (RTCOD).
  - Catalog of Approval Requirements Document (CARDS) (including Operational Capability Objectives).
  - Army Science and Technology Objectives Guide (STOG–77).
  - Required Operational Capability (ROC), Development Plan (DP), and Materiel Need

(MN) documents, Training Device Requirements, and DA-approved QMDOs, ADOs, SDRs, and QMRs.

- HQ, DARCOM objectives, policies, and guidance provided by the annual DARCOM Planning Guidance document, the DARCOM Integrated R&D Plan, DARCOM RDTE program guidance, and DARCOM Five Year Defense Plan (FYDP).
- TRADOC Combat Development Studies.
- Others, as listed in the Bibliography section.

This Plan considers and is closely coordinated with R&D programs of the following U.S. Army organizations:

- Army Research Office (Engineering R&D group)
- Air Mobility Division, OCRD
- Army Materiel Development and Readiness Command (Aviation group)
- Army Materiels and Mechanics Research Center
- Mobility Equipment R&D Command
- Army Aeromedical Research Laboratory
- Ballistics Research Laboratory (BRL)
- Human Engineering Laboratory (HEL)
- Natick R&D Command
- Armament Command (ARMCOM)
- Electronics Command (ECOM)
- Missile Command (MICOM)
- Troop Support Command (TROSCOM)

In particular, activities are coordinated in the areas of Human Factors, Avionics, Ground Handling, and Weapons where performance requirements necessitates the integration of these factors into the total airmobile system, but where mission responsibility for R&D is in or shared with another commodity command or corporate laboratory.

The Plan is in consonance with foreign R&D and related activities, both from the standpoint of threat from a potential enemy and exploitation of Allied developmental efforts. The latter is achieved by active participation and communication with NATO countries through the Advisory Group for Aerospace Research and Development (AGARD) and The Technical Cooperation Panel (TTCP).

The Plan describes research, development, test, and engineering activities appropriate to Army aviation from fundamental research through operational system development. A description of RDT&E programs is included in Army Regulation 705–5. Because of the dependence of new structural and propulsion concepts on concurrent development of advanced manufacturing methods for proof of viability and economical fabrication of components, programs normally falling under the category of Manufacturing Methods and Technology (MMT) Engineering Measures are included in this Plan. MMT as a part of Procurement of Equipment and Missiles, Army (PEMA) is described in Army Regulation 37–100–72.

This Plan includes a Resources Required (RR) section that describes the funding and manpower requirements to accomplish the technological improvement goals identified in the Plan. Also included in most of the technology sections is a subsection on Laboratory Project Selection Process. This process provides Laboratory management with a systematic project selection procedure. The process is described in detail in the Technology Introduction section and is referred to as OPR-Objectives, Priorities and Rationale.

[illegible]

Planning is defined as selecting the appropriate organizational objectives and policies, determining the technical potential to satisfy them, and establishing procedures and methods for achieving those objectives. Technological forecasting, which is an implicit element of the planning process, can be approached by two different methods: (1) "exploratory" forecasting of technology, conjectural in nature, that seeks to project technology parameters from a base of accumulated knowledge in relevant areas (see figure GI–1); and (2) "normative" forecasting of technology, deterministic in nature, that is constrained by the objectives of future requirements (see figure GI–2). Generally, the latter approach is followed in the preparation of this Plan. In this process, future systems goals are identified and assessed to determine technological requirements (voids). By analyzing these requirements regressively through the

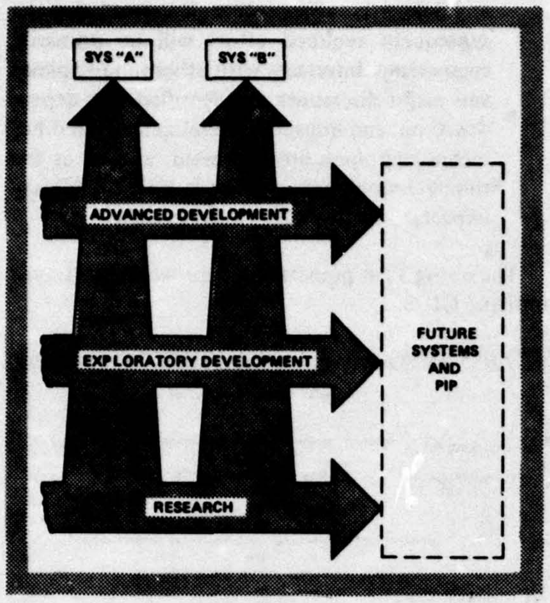


Figure GI–1. Exploratory forecast.

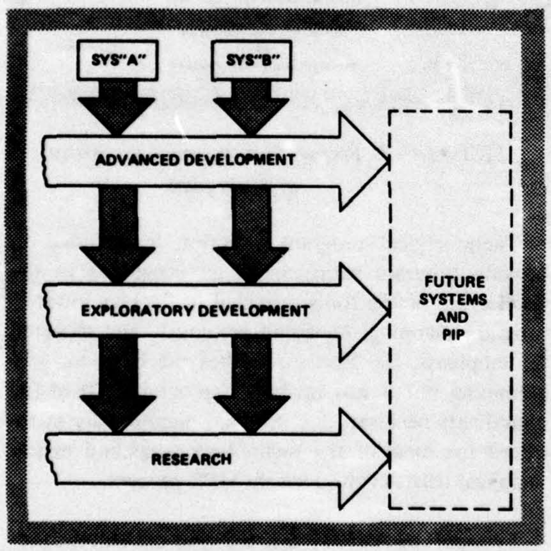


Figure GI–2. Normative forecast.

R&D cycle, specific discipline and functional research requirements are identified, which then become the elements from which R&D programs can be developed. This process has been typed "demand pull," since technological advance is generally accelerated by responding to specific needs. The two types of forecasting are complementary, not competitive, and both should be used. Consequently, while the motivating forces that directed this Plan are air mobility mission requirements, it is also based on careful analyses of past experience and observation, measurement, and interpretation of data, trends, and interactions of aviation technology.

Research and development planning cannot ignore future opportunities for producing technological advancements. It is worth noting that future threats and military operations are more affected by technological events than by the methods and tactics of previous situations. Therefore, the Plan reflects not only the response to the currently projected capability requirements, but also the need for a technological base that will stimulate innovative and imaginative airmobile missions, functions, and concepts.

Considerable uncertainty occurs in long range planning where some of the alternatives cannot be forecast. Technological breakthroughs, variations in threat projections, and fiscal constraints are areas of greatest uncertainty. Within the limitations of such uncertainties, this Plan provides for integrating the requirements for research to fill technical gaps and avoid nonessential duplication.

Current R&D efforts in Army air mobility are directed primarily toward the development of a family of vertical and short takeoff and landing aircraft to fulfill identified mission requirements for the five basic land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication. Efforts are conducted in physical, mathematical, environmental and life sciences, and in low-speed aeronautics, air-breathing propulsion, aircraft armament, vulnerability, survivability, crew protection, and support equipment. These efforts extend also into the fundamental research areas to generate increased knowledge for future air mobility concepts.

The approach taken for the preparation of the Plan is as follows:

- Desired Army aviation capabilities are identified in the form of projected missions/functions without regard to specific candidate systems and with particular emphasis placed on current DA/DARCOM science and technology objectives.
- All apparent possible ways to perform each mission/function are determined.
- An anticipated IOC date is projected for each mission/function identified above. The most promising concepts/systems to meet the requirements then are identified and discussed.

- The performance requirements and technical problem areas of each concept/system are interpreted in terms of technological requirements in 13 basic and supporting technologies:
  - Aerodynamics
  - Structures
  - Propulsion
  - Reliability and Maintainability
  - Safety and Survivability
  - Mission Support
  - Aircraft Subsystems
  - Weaponization
  - Human Factors
  - RPV Technology
  - Aviation Electronics
  - Manufacturing Technology
  - Mathematical Science
- Each of these 13 technologies was further divided into subdisciplines within which all work objectives can be categorized. The desired performance capabilities of the most probable systems are translated into quantitative technological requirements for each subdiscipline.
- The state-of-the-art of each subdiscipline is defined quantitatively, where possible.
- Technology gaps are identified (i.e., the necessary quantitative improvements for each of these subdisciplines are defined with respect to the performance requirements for each system).
- Technology planning objectives are defined in each subdiscipline based on the technology gaps, technology forecast, and expert opinion regarding future potential based on extrapolation of existing trends. Wherever possible, quantitative improvement goals are defined in the form of key-parameter or quality-trend curves and the quantified objectives are related to the requirements of the future missions. In each area, consideration is given to the important causal factors and relationships with other disciplines and technologies.
- An orderly sequence of events by which the objectives can be attained is defined as a rational flow of activity from research through exploratory and advanced development. The objective is to demonstrate that the desired technology is sufficiently well in hand that the subsequent required effort will be primarily engineering. Interfaces with other subdisciplines and major disciplines are identified. The dependence on, and impact of, developments in other technology areas are addressed, as well as the timing requirements on such interdisciplinary impacts.

The above Plan preparation approach is portrayed in figure GI–3.

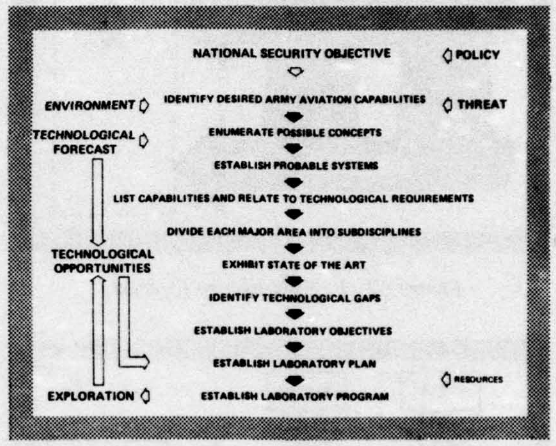


Figure GI–3. Preparation sequence for Army aviation plan.

Technological program direction is included to provide program management an insight as to the application of the tools provided in the Plan towards program planning. As stated previously and repeated for emphasis, the Plan establishes the basis for programming but is not in itself a program. All of the ingredients necessary for program planning are introduced for most of the technology areas and major technical trusts evolved via the OPR process.

Synopses of AMRDL 6.1, 6.2, and 6.3 current projects, and some AVSCOM projects, have been included in the applicable technological sections with FY77 Command Schedule funding shown for the various projects.

Progress in improving the performance of Army aircraft is paced by the technological advancements in the 13 basic and supporting technologies discussed above. Advances in state-of-the-art technology can only be made if the technology is validated by component or system demonstration in actual or simulated flight conditions. The Advanced Technology

Demonstrator section of the Plan discusses the technological advances which will be validated on demonstrator aircraft or by simulation.

The documentation format is described in figure GI–4. The development of air mobile systems is first described in the system sections of the Plan. Technological discussions and program directions with objectives, in response to systems needs and past trends are then described in the technologies sections. Finally, resource requirements to achieve these objectives are discussed.

The Plan is published in an unclassified edition and is supplemented by a classified annex which contains CONFIDENTIAL material on some of the systems and topics as listed in table GI–A.

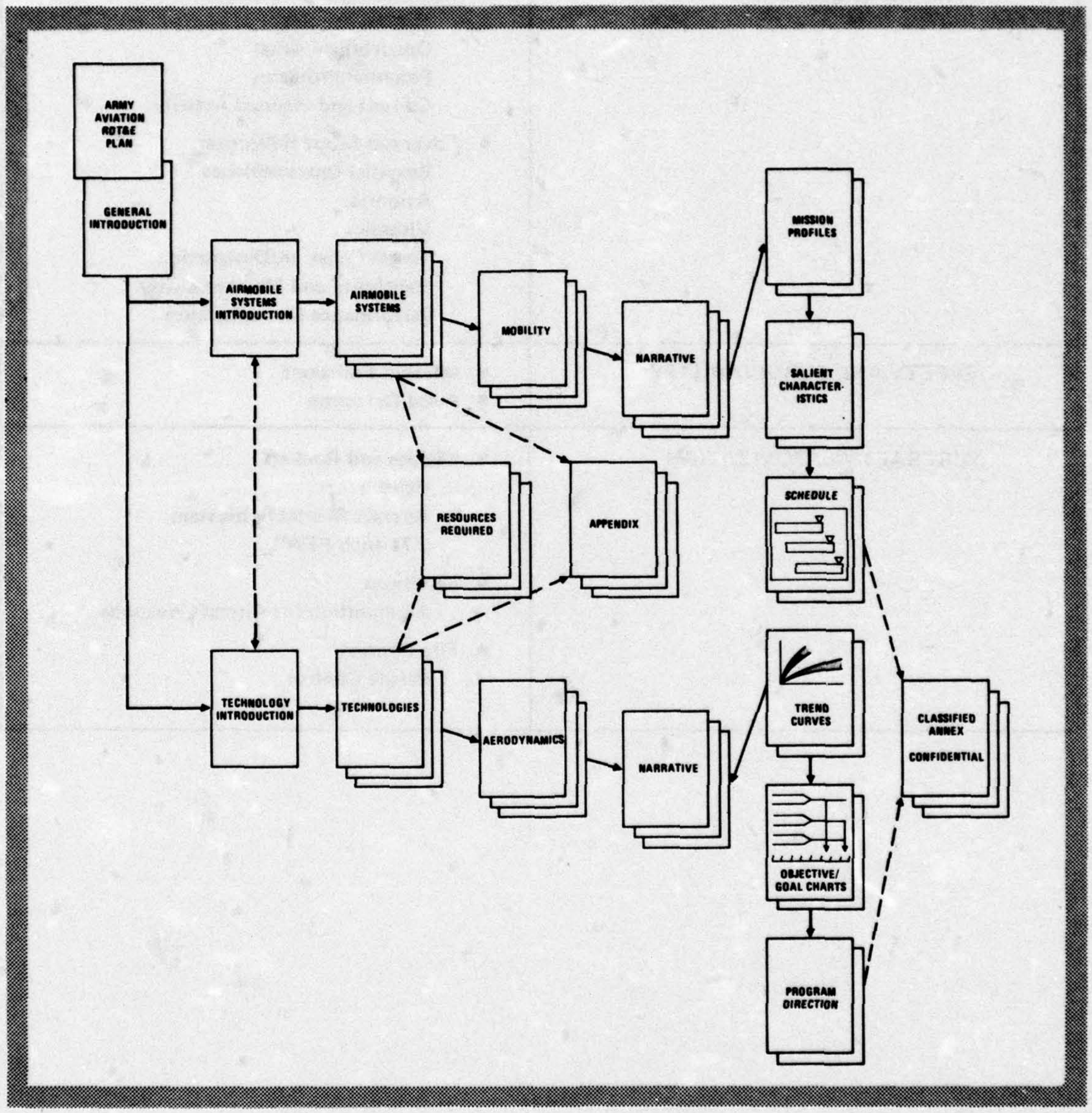


Figure GI–4. Document format.

TABLE GI–A

CLASSIFIED TOPIC LISTING

RDT&E PLAN SECTION	TOPIC
AIRMOBILE SYSTEM INTRODUCTION	• Threat • IOC Dates
AIRMOBILE SYSTEMS	• Advanced Attack Helicopter Mission Profiles Opportunity Areas Potential Problems Current and Planned Activity • Advanced Scout Helicopter Essential Characteristics Avionics Visionics Target Location/Designation Reliability and Maintainability Performance Characteristics
SAFETY AND SURVIVABILITY	• Infrared Emissions • Aural Detection
AIRCRAFT WEAPONIZATION	• Missiles and Rockets Hellfire Aircraft Rocket Subsystem 2.71-Inch FFAR • Munitions Ammunition for Aircraft Weapons • Fire Control Missile Control

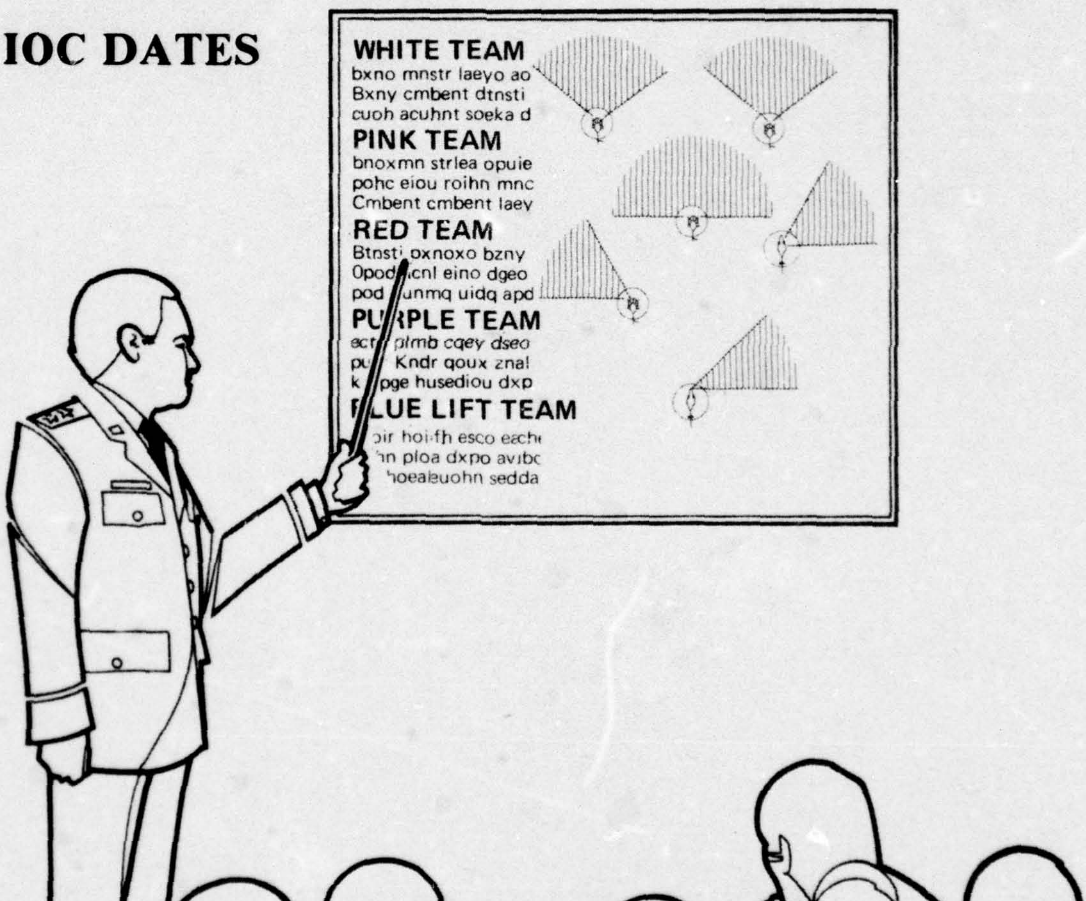
ARMY AVIATION SYSTEMS REQUIREMENTS

THREAT

LAND COMBAT FUNCTIONS

MAJOR THRUSTS

IOC DATES



The use of air vehicles by ground forces has added another dimension to the battlefield by enhancing the ability to conduct land combat functions. The traditional functions of land combat include mobility, intelligence, firepower, combat service support, and command, control, and communication. Use of Army aviation by ground forces is based on certain fundamental concepts of employment that include the following:

- Aircraft are integrated into ground units. Under this concept, aircraft are considered equipment used as an integral part of land combat. The use of airspace is transitory and directly related to the performance of land battle.
- Army policy is to assign aircraft to the lowest user level that can demonstrate a fulltime use of the aircraft and that can accommodate and support it.
- The aircraft should perform its functions by placing the least possible burden on the ground element for support.

As a consequence of the above concepts, and as a result of Army experience with aviation in combat, certain additional criteria have been developed that bear directly on required aircraft characteristics. These characteristics for vertical takeoff and landing (VTOL) aircraft include the following:

- The ability to hover out of ground effect at 4,000 ft pressure altitude, 95° F at basic mission weight with a 500-ft-per-min vertical rate of climb and 95 percent normal rated power, thus permitting aircraft to be based close to the tactical user without prepared airfields.
- Adequate speed to ensure timely response, productivity (ton miles per hour, missions per day, etc.), and survivability. Generally, high speeds are desirable but can be costly in terms of power required, design complexity, dynamic component life, and direct costs such as forward area refueling support, airframe costs, maintenance costs, and size/weight of aircraft. As such, high speeds must find justification in terms of reduced aircraft losses and increased cost effectiveness of overall mission performance.
- All-weather, full-instrument flight capability providing effective organic aviation support to the ground soldier under any climatic condition in which he fights.
- Crashworthiness, requiring prevention of post-crash fires, energy-absorbing structures for crash impact, and crew restraining devices to enhance survival.
- Survivability, requiring the ability to survive enemy fire without high penalties in aircraft weight, size, or costs.
- Terrain flying, requiring the ability for flight in such a manner as to utilize the terrain, vegetation and man-made objects to enhance survivability by degrading the enemy's ability to visually, optically, or electronically detect or locate the aircraft. This requirement is applicable to cargo handling aircraft systems as well as combat oriented systems.

The three operational concepts require that Army aircraft meet the user's functional needs, possess characteristics that permit the user to have ready access to the aircraft, and not place great demands on the user for support. Considerations such as these are the genesis of Army requirements documents for such characteristics as VTOL, simplicity, reliability, and maintainability. For the aircraft characteristics, the requirement to hover originates directly from the need to base aircraft with the user, be immediately responsive in terms of time, and negate demands on the user in airfield construction or protection. The aircraft should be capable of existing within the normal perimeter of tactical ground units. This concept of livability translates directly into characteristic requirements for low-disc-loadings and low noise levels. Related characteristics are those of agility and maneuverability in the air and on the ground.

The concept of minimal special support generates characteristics related to ground support maintainability, simplicity, and reliability. The effect of these characteristics on capability must be carefully assessed through tradeoff studies. Advances in the state-of-the-art must provide the additional benefits without the penalties that would reduce the effectiveness of Army aviation.

[redacted]

The Army in the future will have a continuing need for new and improved materiel systems to enable it to fulfill its role in the national defense. In order for a proposed weapon system to prove a worthwhile addition to the Army inventory, careful consideration of potential adversary capabilities and intentions must be a part of the development process. Simply stated, the Army has to be aware of threat and take measures to reduce or negate it.

For R&D considerations, we must know the capability differences between our systems and those of a possible enemy, and must know as much as possible about how their materiel operates and mode of deployment. Furthermore, we must consider these factors up to 10–20 years in the future. The threat is "what you shoot at and what shoots at you," and any countermeasures which would reduce the effectiveness of our systems. It is a key facet of the developmental process and is applicable throughout the life cycle of Army materiel.

As illustrated in figure AI–1 (a graphic side view of the threat as it might exist on a high threat battlefield), the Army pilot is being trained to negate the impact of the threat as much as possible by tactics and flying techniques. It is not enough by itself. In order to be mission effective, the same Army pilot must have the equipment to do the job. Close coordination between developer and user of Army Aviation Systems ensures not only awareness of the threat but acting on the threat.

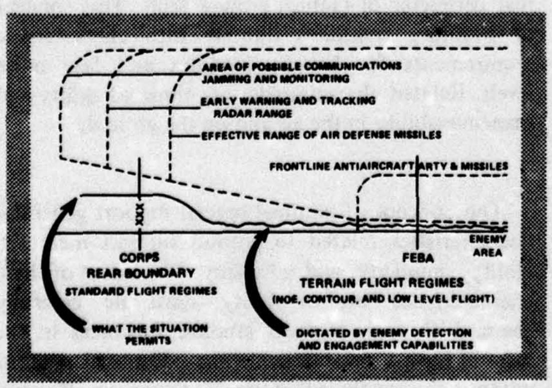


Figure AI–1. Threat profile.

Threat as a generic term is vast when applied to Army aviation. It encompasses hostile weapons such as ground based guns, surface to air missiles (SAM), and air to air guns/missiles, and also those systems and techniques which could negate or lessen our abilities such as electronic warfare (EW). Since the threat is not limited to fielded system but includes those weapons which will be fielded in the future, the potential impact of ignoring the threat in the R&D process becomes disastrous.

The latest threat information available has been used in the generation of this Plan. It is based primarily on the threat analysis document "Threat to US Army Aviation Systems" (U) prepared by Department of the Army, Assistant Chief of Staff Intelligence. The threat is not static however, and is constantly updated with the information being used in actual R&D activities.

Details of threats used in the generation of the Plan contain classified material and are summarily presented in the classified annex to the Plan.

[redacted]

The application of operational airmobile systems to the various land combat functions is shown in figure AI–2 and discussed in detail in the following section – Airmobile Systems. The matrix of figure AI–2 as well as the discussion material is based on the five land combat functions of mobility, intelligence, firepower, combat service support, and command, control and communication. The airmobile systems are categorized as operational systems, developing systems and R&D planning concepts. There is mission overlap between some of the functions which, in turn, results in the same aircraft applicability.

[redacted]

A study of the deficiencies and shortcomings of current Army aircraft discussed in the airmobile section reveals many areas of commonality, such as lack of survivability, high life-cycle costs, inadequate performance, etc. A similar analysis of potential problem areas for future systems results in similar common problem areas. Solution of all the problem areas would require greater resources than may be available to the DARCOM. Emphasis has been placed on the

LAND COMBAT FUNCTION	MISSION	OPERATIONAL SYSTEMS	DEVELOPING SYSTEMS					R&D PLANNING CONCEPTS						
			AAH	UTTAS	ASH	RPV	CH-47D*	HLH	OV-X	SUR/VTOL	AAWS	LAH	LUH	MMAS
MOBILITY	UTILITY	UH-1		■									▨	
	MEDIUM LIFT	CH-47					■							
	CARGO TRANSPORT	CH-54						▨						
INTELLIGENCE	RSTA/D	LOH			■					▨				
		OV-1D				■			▨					
FIREPOWER	TACTICAL MOBILITY	UH-1	■									▨		
	DESTROY	AH-1	■								▨			
COMBAT SERVICE SUPPORT	UTILITY	UH-1		■									▨	
	MEDIUM LIFT	CH-47					■							
	CARGO TRANSPORT	CH-54												
COMMAND, CONTROL & COMMUNICATION	AVIATION SUPPORT	LOH											▨	▨
		UH-1		■									▨	

*MAJOR MODERNIZATION PROGRAM

Figure AI–2. Land combat function mission systems.

DA specified science and technology objectives, with the greatest effort being applied in the areas where technological breakthroughs or advances would significantly improve the combat capability of current or developing aircraft systems.

As a result of the emphasis placed upon the current major thrusts, R&D efforts may resolve or reduce the significance of a particular problem. At that time, a realignment of the thrusts should take place to recognize new areas of highest potential payoff. The identification of problems presented in this Plan provides a method of identifying these areas.

IOC DATES

IOC dates for developing airmobile systems and R&D concepts used in the development of this Plan are CONFIDENTIAL and are provided in the classified annex to the Plan.

INTRODUCTION

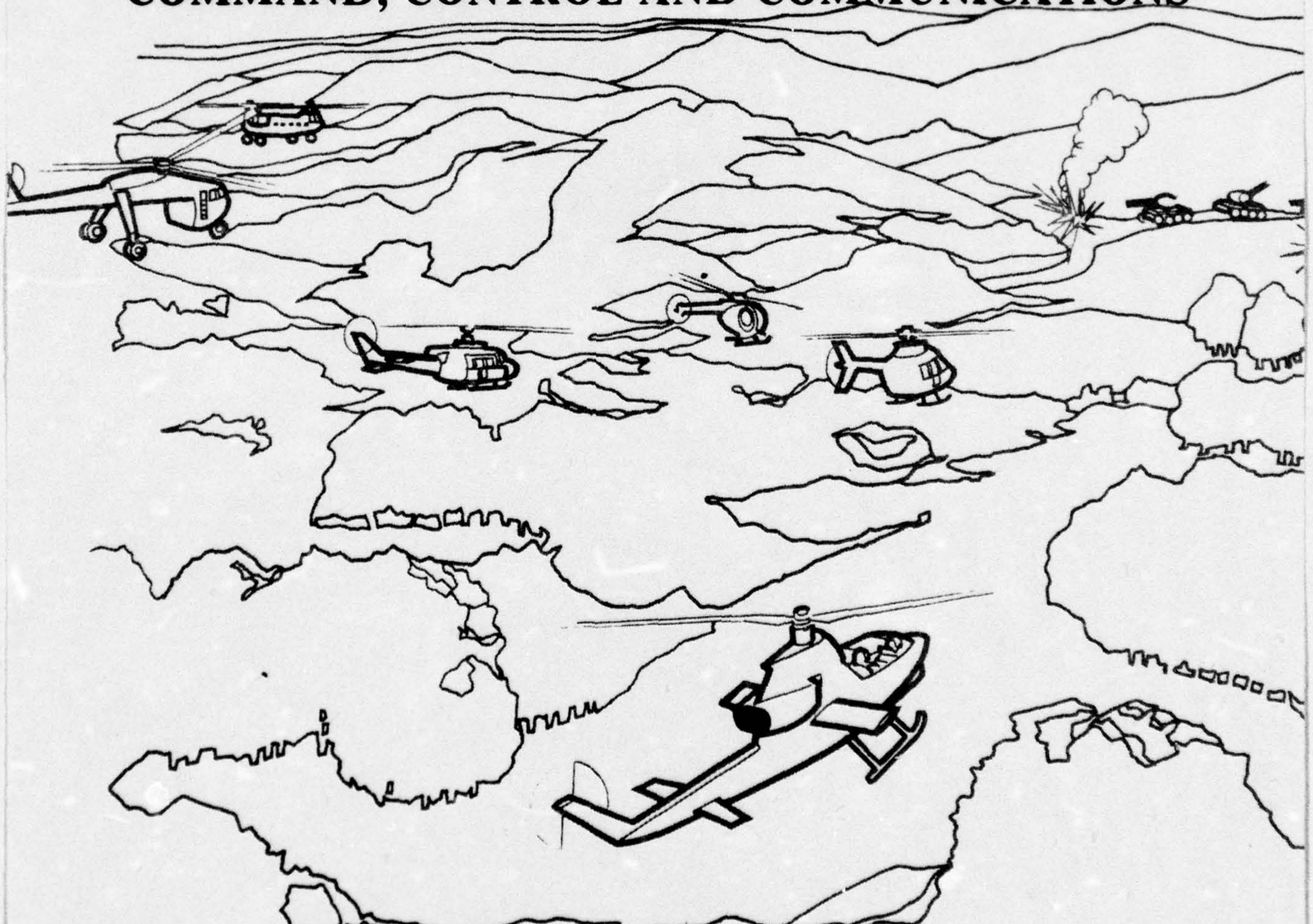
MOBILITY

INTELLIGENCE

FIREPOWER

COMBAT SERVICE SUPPORT

COMMAND, CONTROL AND COMMUNICATIONS



INTRODUCTION

The objective of Army aviation units are to augment the capability of the Army to:

- Conduct prompt and sustained land combat;
- To provide the ground commander with mobility, firepower, and staying power needed to win the first battle;
- To help the ground forces to win while outnumbered.

In the future, Army aviation units will fight as part of the Combined Arms Team in a high threat environment. To provide the Army with this capability, the R&D efforts must be aimed at system development rather than undivided aircraft development.

This section of the RDT&E Plan presents a brief summary of the Army aviation current systems, developing systems and R&D planning concept systems (projected future aircraft system). The section is organized around the five basic land combat functions as discussed in the Airmobile Systems Introduction section. As one would expect, there is mission overlap between some of the various functions which, in turn, results in the same aircraft applicability to various functions. This is presented graphically in figure AI–2.

MOBILITY

GENERAL

The demand for greater mobility has continuously increased throughout the history of warfare. The airmobile capability that began in the Korean conflict and proved so valuable during the recent experience in Vietnam will be equally, if not more valuable in the future. The ability to quickly redeploy light mechanized units and mobile air defense artillery by air and to transport assault troops, weapons, and equipment around the battlefield, over obstacles, and bypass enemy strong points should prove particularly valuable in any future conflict.

For squad-size units and small weapons, the utility mission of the mobility function is currently being performed by the UH-1, which will be replaced by the Utility Tactical Transport Aircraft System (UTTAS). The UTTAS will lift a basic tactical infantry squad or its transport equivalent of externally or internally loaded bulk cargo. For units of larger size or heavier weapons, the CH-47 provides the necessary mobility, medium lift. Because of its vulnerability, the CH-47 is rarely used in the combat assault role but provides maneuverability to the fire support elements and other supporting units. The CH-47 Modernized Medium Lift Helicopter (MLH) (to be designated as the CH-47D) is projected to replace the CH-47 for payloads in the 7- to 10-ton range. For large outsized loads requiring external slinging, the CH-54 helicopter is currently used. For future R&D system planning, the Heavy Lift Helicopter (HLH) System is projected for lift capability of 20 tons up to 50 tons.

CURRENT MOBILITY OPERATIONAL SYSTEMS

UTILITY MISSION SYSTEM

The current standard Army aircraft performing the utility mission of the mobility function is the UH-1H helicopter. A discussion of the UH-1H is presented in table AM–A.

MEDIUM LIFT MISSION SYSTEM

The CH-47C is the current Army medium lift helicopter (MLH). A discussion of the CH-47C is provided in table AM–B.

CARGO TRANSPORT MISSION SYSTEM

The CH-54B is the current Army cargo transport helicopter. A discussion of the CH-54B is presented in table AM–C.

TABLE AM–A
GENERAL UTILITY HELICOPTER DESCRIPTION

GENERAL	• The current standard utility helicopter is the Bell UH-1H which is the latest in the series of UH-1 aircraft.
PRESENT CAPABILITIES	• The UH-1H is capable of carrying 8 to 10 combat equipped troops, or 2,400 lb of cargo more than 250 miles at a cruise speed of 100 knots. It has an external cargo hook capable of lifting 4,000 lb and is equipped for IFR flight. Large sliding doors and unobstructed cargo space allow rapid loading and unloading of internal cargo and combat troops.
DEFICIENCIES AND SHORTCOMINGS	• The major deficiency of the UH-1 helicopter has been its inability to achieve the slated performance and payload, with reserve power for OGE vertical climb at higher density altitudes. The addition of a copilot, two door gunners, aircrew armor, and associated equipment, together with high density altitudes, has reduced the effective payload of the UH-1 to six to eight combat equipped troops, or less than 2,000 lb of cargo. Also, the UH-1 has a distinctive noise signature (blade slap) easily identifiable with this helicopter. The extensive use of honeycomb structural panels throughout the airframe has made sheet metal repair time consuming and difficult. The maintenance MMH/FH ratio is excessive and the MTBF of major components is inadequate. The installation of crashworthy fuel cells and IR-suppression devices have increased its survivability, but it is still marginal.
FOLLOW-ON SYSTEM	• The UH-1H will be replaced by the UTTAS as the Army utility helicopter.

TABLE AM–B
CURRENT MEDIUM LIFT HELICOPTER DESCRIPTION

GENERAL	• The current Army medium lift helicopter is the Boeing-Vertol CH-47C.
PRESENT CAPABILITIES	• The CH-47C is capable of carrying 34 troops, or an internal cargo of 10 tons for a 100-nautical-mile radius mission, at 120 knots. It can also lift 23,300 lb for a 20-nautical-mile mission at 100 knots. It has a 30-ft-long cargo compartment capable of carrying two three-quarter-ton trucks or other large bulky cargo. It has an external cargo hook of 10-ton capacity that may also be used for towing operations. The aircraft has a self-contained APU and is fully IFR-equipped.
DEFICIENCIES AND SHORTCOMINGS	• Operating costs of the current CH-47 fleet are excessive. A and B series aircraft are approaching planned retirement and their lift capability is less than optimum to provide airmobility support to the ground forces. Safety and survivability and RAM features of the existing CH-47's are inadequate and need to be upgraded.
FOLLOW-ON SYSTEM	• The LTTAS was planned to replace the CH-47C; however, this role was abandoned when the LTTAS effort was terminated in 1970. The Army has reviewed the CH-47 operational capability and concluded that a valid requirement exists to sustain a MLH fleet well into the 1990's. As a result, the modernized CH-47(D) is now programmed to replace the CH-47 fleet. This program has DA approval and a contract is being negotiated with Boeing-Vertol for engineering development of 3 prototype aircraft.

TABLE AM–C
CURRENT CARGO TRANSPORT HELICOPTER DESCRIPTION

GENERAL	• The current standard Army cargo transport helicopter is the Sikorsky CH-54A. The CH-54A is also in service.
PRESENT CAPABILITIES	• The CH-54B is equipped with a four-point load suspension system of 20,000 lb capacity and a single-point hoist with a capacity of 25,000 lb. It can carry a 25,000 lb external load for 20 nautical miles at 95 knots, or a smaller load of 15,000 lb for 120 nautical miles. Although its primary mission is external cargo, the CH-54 does have a detachable pod that can be readily attached or detached for internal cargo. The aircraft features a load-facing crewman who has limited control for hook-up and detaching of external loads. The aircraft has a self-contained APU and is fully IFR-equipped.
DEFICIENCIES AND SHORTCOMINGS	• The CH-54B, operational readiness averages only 75%. Contributing factors are low field density and an out of production status. Additionally, its maintenance MNH/FH ratio and SFC are relatively high, its cost per ton mile is higher than surface modes and it cannot carry passengers and external loads simultaneously.
FOLLOW-ON SYSTEM	• There is currently no system being developed to replace the CH-54B although Advanced Technology Components of a HLH system have been under development.

DEVELOPING MOBILITY SYSTEMS

UTILITY MISSION SYSTEM

General. The Utility Tactical Transport Aircraft System (UTTAS) will process essential performance, maintenance, and physical characteristics required to operate primarily as a squad carrier for airmobile operations in all intensities of conflict in the assault and resupply phases and secondarily as combat support and combat service support for other units and agencies. It must be capable of performing its intended missions under adverse geographical and environmental conditions.

The UTTAS will be transportable by sealift or airlift with minimum disassembly. Its physical dimensions will allow two aircraft to be loaded in a C-141 or one on a C-130. Preparation time per UTTAS will not exceed 5 manhours within a 1.5-hr period and reassembly will not exceed 5 manhours within a 2-hr period. The actual loading time for one UTTAS will not exceed 30 min.

Other characteristics will include sufficient agility and maneuverability to permit safe nap-of-the-earth operation at 150 knots formation flight under visual conditions, and instrument flight (day and night) up to the aircraft service ceiling.

Salient Characteristics. Performance, reliability and maintainability characteristics and physical characteristics of UTTAS are presented in tables AM–D and AM–E, respectively.

Throughout the preliminary design study and analysis resulting in the configuration described in table AM–E, the primary objective was to produce a UTTAS with maximum survivability. To achieve this, three major parameters were considered.

- Signature reduction through infrared suppression will be engineered into the system by reducing surface emissivity of the engine group. A removable kit-type IR emission suppressor will be provided for the engines. The structural design of the baseline aircraft presents a minimum radar cross section by means of geometrical shaping to eliminate specular surfaces and corner reflectors. Particular attention is required in main rotor and tail rotor design to preclude blade slap, rotational, and tip vortex produced noises.

TABLE AM–D
UTTAS PERFORMANCE/RAM CHARACTERISTICS

OPERATIONAL CAPABILITY	• Low life cycle cost with squad lift capability.
PERFORMANCE CHARACTERISTICS	• Hover oge at 4000 feet 95°F, vroc 450-550 fpm at 95 percent intermediate power, zero wind. • 145-175 knots cruise speed. • Three-man crew. • Payload 11 troops or 2,640 pounds. • 2.3 hours endurance. • Safe one-engine inoperative capability. • All-weather day and night mission capability.
MAINTENANCE	• Fault corrective maintenance Unit and intermediate levels not to exceed 2.8 maintenance manhours per flight hour (MMH/FH) (exclusive of avionics and weapons subsystems). • Inspections and servicing Daily/preflight, periodic, and special inspections and servicing not to exceed 1 MMH/FH. 300 hours between periodic inspection. • Overhaul Mean time between removal of critical components greater than 1,500 hours. No major overhaul intervals by design less than 4,500 hours.
RELIABILITY	• Mission reliability greater than 0.986909*. • Flight reliability greater than 0.999952*. • Operational availability greater than 82%**.

*Based on completing a 1-hour mission while being supported by the maintenance environment found at any level of conflict.

**Utilizing the combination of modular components, diagnostic fault detection equipment, and simplified maintenance procedures.

- Vulnerability as established by analysis, considering crew and vital component protection, resulted in a protective armor system for the baseline vehicle contained within the normal contours of the aircraft and retaining the maximum visibility afforded from the crew position. Critical elements, components, and equipment in the fuselage of the baseline configuration will be arranged, grouped or routed to achieve the minimum probability of being hit by ground fire small arms projectiles. Where critical items cannot be adequately protected through location, grouping, etc., armor protection devices have been incorporated. This armor for component protection has been included in the empty weight of the baseline configuration. Small items essential to continued flight and control of the baseline vehicle (i.e., control torque tubes, rod ends, engine governors, bell cranks, etc.), are to be afforded maximum protection from damage by enemy action by replacing such components with ballistic-resistant materials or by placing them behind heavy structures of noncritical items or components. When control system components are duplicated, they are to be separated to avoid damage by the same projectile.

TABLE AM–E
UTTAS PHYSICAL CHARACTERISTICS

FUSELAGE/CABIN ARRANGEMENT	• Fuselage arrangement, structural and functional, shall be such as to accommodate the crew (pilot, copilot, and crew chief/gunner) and troop payload (11 combat-equipped troops @ 240 pounds each or an equivalent payload). A fourth crew station will be provided and occupied by the eleventh passenger or an additional gunner. • The UTTAS shall incorporate a 7000-pound capacity external cargo hook and provisions for mounting a 600-pound capacity rescue hoist. • Cabin arrangement shall incorporate 10 troop seats (minimum width of 20 inches) and two gunner positions. The cabin will also accommodate four to six standard folding, rigid pole litters. The floor will be of a nonskid material capable of supporting distributed loads of 300 psf. • Doors will permit rapid troop ingress and egress and in conjunction with the cabin arrangement will permit 11 combat-equipped troops to load or unload in less than five seconds.
LANDING GEAR	• Landing gear configuration will be wheeled with brakes, flotation capability or being towed across soil with a CBR of 2.5, minimum ground-to-aircraft fuselage clearance of 16-20 inches, ground-to-floor height of not more than 28 inches, and operational capability of 12° slope landing.
FUEL SYSTEM	• The fuel system shall comply with the latest military standard for crashworthy design. The system will have single-point pressure fueling and defueling, gravity fueling and defueling as well as closed-circuit fueling. It will accept range extending tanks.
POWERPLANT	• The UTTAS powerplant will use the advanced technology that has been developed by the Army's 1500 HP advanced technology gas turbine demonstrator engine program. The engine will be developed by General Electric in accordance with MIL-E-8593 as modified by the Army. The Army designation of the GE 12/TIAI engine is T700-GE-700.
DRIVE SYSTEM	• The drive system consists of nose, main, intermediate, and tail rotor gear boxes with associated shafting. • The main gear box combines the output of the two T700-GE-700 engines with a 120 percent rating of the combined output of the engines at 4000 feet, 95° F conditions. • The system will incorporate the maximum degree of damage tolerance practical. All gear boxes will be capable of 30 minute operation at the power required for cruise flight, following total loss of the lubrication subsystem.
COMMUNICATION SYSTEM	• The communication system will consist of the following equipment with retransmission capability between any two radios: VHF-FM radio set (30.0 to 79.95 MHz) – Clear and secure voice communication UHF-AM radio set (225.0 to 399.5 MHz) – Clear and secure voice communication VHF-AM radio set (116.0 to 149.975 MHz) – Clear voice communication • The system also provides aircraft intercommunication and serves as a data link with the tactical fire direction system and consists of the following equipment: AN/ARC-114 radio set — C-6533 control unit AN/ARC-115 radio set — TSEC/KY-28 voice security set AN/ARC-116 radio set
NAVIGATION SYSTEM	• The navigation system will provide for enroute and terminal navigation under visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) with single ship instrument flight capability, at altitudes that insure terrain clearance, and single ship instrument approaches to landing at terminal areas equipped with landing approach aids. The system will include the following: LORAN navigation system providing continuous digital readout of present position in universal transverse mercator (UTM) coordinates and distance to selected destination point. It will also provide information to maintain a selected course to destination. An automatic direction finder set AN/ARM-89. VHF/FM homing set. A tactical landing system incorporating distance measuring to touch down. Complete provisions for civil airways navigation and instrument approach equipment, (i.e., VOR localizer, glide slope, and marker beacon).
IDENTIFICATION	• The identification system will provide identification friend or foe (IFF) with selectable identification feature (SIF) and secure mode operations. The system will include AN/APX-72 and computer KIT-1A/TSEC.
WEAPONS SYSTEM	• There will be two easily installed and removable pintle-mounted medium machine guns, one mounted on each side of the aircraft.

- Safety and crashworthiness studies of accident investigation reports indicate that improvements in crash survival for crew and troops can be made if consideration is given in the initial aircraft design. The characteristics being emphasized in the UTTAS development are energy absorbing structure, maintenance of livable space, elimination of missile hazards, emergency egress, and elimination of post-crash fire.

Figure AM–1 shows the Sikorsky version of the UTTAS and figure AM–2 the Boeing version.

Key Operational Capability. The key operational capability of the UTTAS will be its low life-cycle cost with squad lift capacity. Inherent in this capability is design-to-cost and R&M improvements over the UH-1.

Opportunity Areas. UTTAS acquisition will provide the Army an aircraft that can accomplish missions throughout the range of temperature/altitude combinations where United States forces can reasonably be expected to operate. The UTTAS will satisfy requirements for an assault helicopter in the projected timeframe. In addition, it will have a higher degree of survivability in all intensities of conflict and provide a system that can be based, operated, and maintained in forward areas where it will be more responsive to the needs of the users. Consequently, the UTTAS will provide improvements in reliability, maintainability, vulnerability, survivability, performance, human factors, air transportability, availability, detectability, crashworthiness, and safety over the UH-1 series. It must be pointed out that R&D trends toward horsepower/pound, dollars/pound, etc., are not specifically involved in the UTTAS development. Except for the specific fuel consumption of the T700-GE-700 engines, the strategy of detailed trends and goals remains with the contractors. Specifically, that trend which permits the UTTAS to meet the requirement of the RFP and perform the primary mission is required.

In addition to the capabilities shown in table AM–D, it is noted that the UTTAS will have a 7000-lb external cargo hook capability that, generally speaking, will be usable in many ambient conditions. External lift capability is only limited by the maximum alternate gross weight of the UTTAS, which will be about 4000 lb above the mission gross weight. In other words, the UTTAS will be able to hover out of ground effects with external payloads of 4000 lb plus the 2640 lb of internal payload and mission fuel at sea level, 95°F conditions. Of course, fuel, troops, internal and external payload tradeoffs can be made as long as center-of-gravity limits and maximum alternate gross weight limits are not exceeded. Maximum range without ferry tanks (using full internal fuel) is 2.3 hr at sea level standard day temperatures.

Potential Problems. There are no major problems at this time and none are expected because of the following reasons. The UH-1 helicopter was designed in the early 1950s and was the first turbine-powered helicopter to see wide operational application. The UH-1 was a product of a specialized industry with technological breadth well below that of the rest of the aviation industry. Since that time, the helicopter industry has developed technological capabilities and breadth spanning the scope and disciplines of the aerospace technology and engineering field. Improvements incorporated into the UH-1 during the last ten years in part reflect this maturity. These broad advances have set the stage for major potential advances in effectiveness and efficiencies for the next generation of helicopters. A low risk program is further enhanced by the competitive prototype development effort, wherein Boeing-Vertol and Sikorsky each develop and test candidate designs to be evaluated by the Government, and a single contractor is then selected for production.

Current and Planned Activities. Figure AM–3 shows the schedule for the UTTAS program.

Tradeoff studies to be performed by the airframe contractors during engineering development include a Central Integrated Checkout System (CICS) diagnostic system, aircrew armor, personnel/cargo handling subsystem, instrumentation, survivability/vulnerability, aircraft fault warning subsystem, noise control program, crew station geometry, and a producibility study.

The UTTAS development program consists of two phases, Basic Engineering Development (BED) and

Figure AM–1. Sikorsky UTTAS. (YUH–60A)

Figure AM–2. Boeing UTTAS. (YUH–61A)

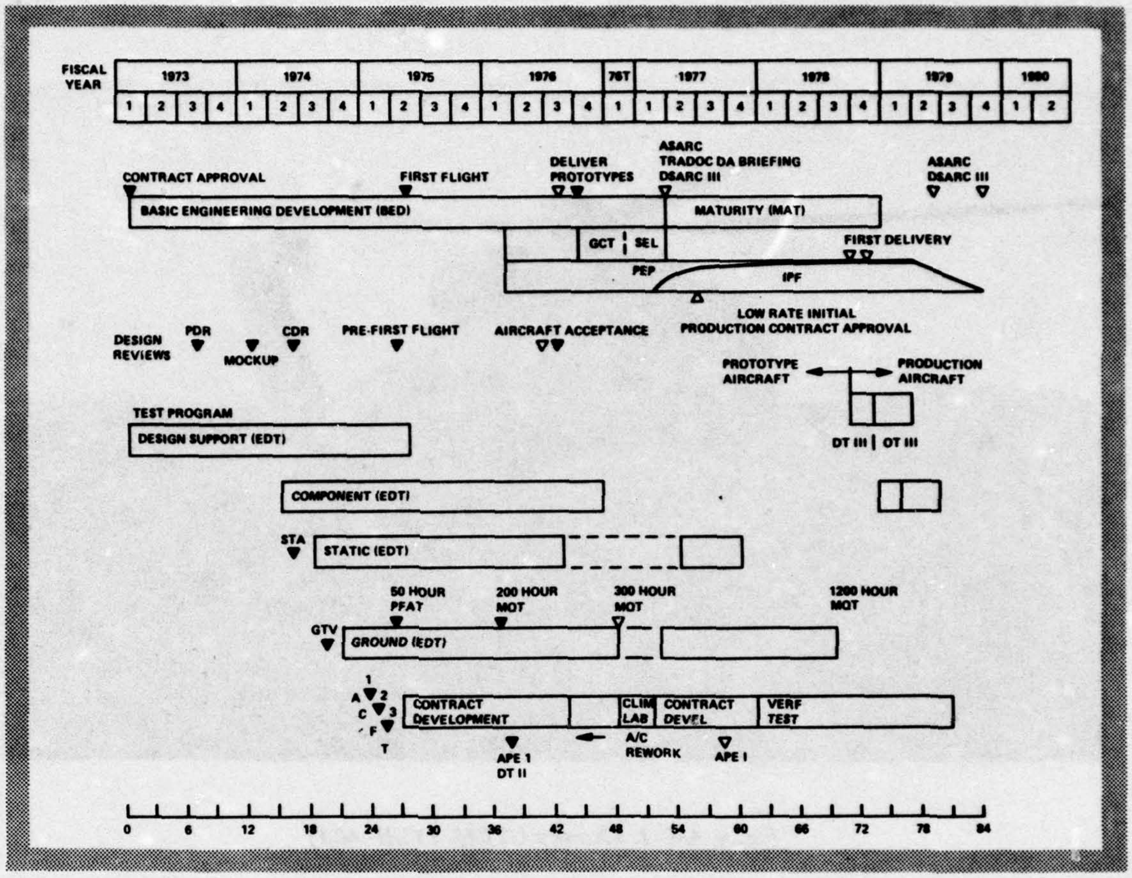


Figure AM–3. UTTAS schedule.

Maturity (MAT). The BED phase is the competitive portion of the program, while the MAT phase is conducted with the selected design. During the competitive phase, both Sikorsky and Boeing-Vertol will be required to build three flight-test prototypes, one Ground Test Vehicle (GTV) and one Static Test Article (STA). The aircraft will be used by the competing contractors for demonstration and airworthiness qualification in preparation for the competitive testing. The three aircraft will be delivered for the competitive test, but the GTV and STA will be retained by the contractors for continued qualification and development under Army supervision (see figure AM–3).

The BED phase is divided into three periods: (1) contract award to first flight, (2) first flight to delivery of prototypes for evaluation, and (3) the Government Competitive Test (GCT) as described below:

- During the period from contract award to first flight (27 months) the contractors will design, develop, fabricate, and adequately test the UTTAS to achieve a flight release for the first flight vehicle. Engineering and design data substantiating airworthiness of the vehicle shall be reviewed to ensure minimum risk for the initial flight. EDT-type tests (i.e., design support tests, component bench tests, subsystem tests, static tests, and systems tests) are scheduled during this period.

- Design reviews will be held periodically as required to establish a foundation for airworthiness substantiation and ensure compliance with all airworthiness qualification requirements including human factors, system safety, reliability, maintainability, survivability, and vulnerability. These reviews will include a preliminary

design review, mockup review, critical design review, and pre-first flight design review.

- The major test milestone scheduled for the contract award to first flight period is the completion of the 50-hr Preliminary Flight Approval Test (PFAT) in accordance with the requirements of MIL-T-8679.

- Subsequent to first flight, the contractors are allowed 16 months to continue developmental tests to further their design, open the UTTAS flight envelope, and achieve a 200-hr dynamics MQT prior to each turning over three prototypes for Army evaluation during the GCT. EDT testing in this period consists of component bench tests, subsystem tests, static tests, and ground and flight system tests. The first Army Preliminary Evaluation (APEval) is scheduled 4 months prior to the GCT. The Army Preliminary Evaluation flown by Army pilots is programmed during this period to assure that the flight vehicles conform to the design data and assure compliance with the applicable qualification requirements as shown in the Airworthiness Qualification Specification (AQS). In addition to the flight tests, GTV tests to achieve the 200-hr MQT are programmed. An aircraft acceptance design review will be held just prior to the acceptance of the aircraft for GCT. Major test milestone schedules for the first flight period is the completion of the 200-hr MQT.

- The final period of the BED phase consists of the GCT and the continuing development effort of the contractors. During the 10 months the Army is conducting developmental and operational tests (DTII/OTII) and evaluating results, the contractors will use the GTV and the STA to continue system development and qualification testing to achieve a 300-hr MQT on dynamic components and to conclude the static test program. The GCT consists of 715 flight hours (255 hr for OTII and 460 hr for DTII) to be flown on each design. A climatic laboratory survey will be performed during this period on each design at the Eglin AFB test facility.

- At the conclusion of the BED phase, adequate development and operational testing will have been accomplished to assist in the selection of the winning design and allow the award of a limited production contract. The following DT/OT-type tests will have been completed on each of the contractors' designs.

- 480 hr of contractor flight (EDT) tests
- 20 hr of Government flight (DTII) tests
- 1220 hr of contractor GTV (EDT) testing
- 715 hr of Government flight (DT/OTII) tests
- Climatic Laboratory Survey
- 300 hr MQT on dynamic components

Table AM–F is a list of subsystem and dynamic component reliability test hours that are scheduled during development.

During the MAT phase (21 months) the selected contractor and the Army will complete the UTTAS Airworthiness Qualification Program (AQP) and correct any deficiencies/shortcomings encountered during the GCT. The AQP concludes with the Airworthiness and Flight Characteristics (A&FC) test, and RAM and Suitability Test. In addition, the selected contractor is required to achieve a 1200-hr MQT on dynamic components prior to delivery of the first limited production UTTAS, and complete the extensive reliability and maintainability programs to effect compliance with the MN requirements.

DTIII and OTIII tests will be performed on the initial production aircraft.

MEDIUM LIFT MISSION SYSTEM

General. The follow-on system for the current CH-47 fleet will be the CH-47 Modernized Medium Lift Helicopter (MLH) to be designated as the CH-47(D). This is essentially a major modernization effort and, although it is presented under the heading of developing systems for convenience in concept categorization, should not be considered in the same light as a new development project such as the UTTAS and AAH.

Current System. The current CH-47 Chinook Medium Lift Helicopter (MLH) was designed as a transport helicopter with these missions: artillery movement, missile transport, personnel movement, aircraft recovery, medical evacuation, transport of liquid and dry bulk cargo and other combat and

TABLE AM–F
UTTAS RELIABILITY TEST

COMPONENT	TOTAL TEST HOURS	GTV AND FLIGHT TEST HOURS
Main Transmission	8500	2500
Engine Transmission	5500	2500
Drive System Shafting	5500	2500
Tail Rotor Intermediate and Right Angle Transmission	5500	2500
Swashplate	8000	2500
Rotating Main Rotor Controls	5500	2500
Main Rotor Head	5500	2500
Main Rotor Blades	5500	2500
Tail Rotor Hub and Blades	5500	2500
Main and Tail Rotor Control Actuators	4500	2500
Flight Control, Hydraulic, and Electrical Subsystems Components	4500	2500

combat service missions during day, night, and adverse weather conditions. The CH-47 has the capability of carrying cargo internally and/or externally depending on cargo configuration. It was developed in the late 1950s using technology of that era. The CH-47A with a 9600 lb lift capability, was the first aircraft to be delivered in the 1962-1967 timeframe. Later the CH-47B, which incorporated improvements in speed and payload capabilities, was procured as an interim model. It provided an external lift capability of only 9400 lb. This model was followed by the CH-47C which satisfied the Army's requirement for 15,000 lb MLH external payload.

The current fleet has four primary inadequacies: systems operating costs are a support burden on critical Army resources; A and B series aircraft, as currently configured, are approaching planned retirement; the A and B series do not meet the 15,000 lb lift requirement needed to provide air-mobility to artillery and engineer equipment; and the reliability, availability, maintainability, safety and survivability features of all existing CH-47s are inadequate and need to be upgraded to current standards.

Contingency Analysis. The need for MLH capability was recognized to continue through the 1980s. To sustain this capability, it was determined that a modernization and/or procurement program would be necessary.

In 1968, the expected life of an aircraft for planning was 10-15 years. Recognizing the long lead time necessary to bring a replacement system on line, a new project called the Light Tactical Transport Aircraft System (LTTAS) was initiated. This project was subsequently terminated by the Department of the Army when it was determined that the CH-47C lift capability of 15,000 lb at 4000 ft 95° hover-out-of-ground effect with 200-500 FPM rate of climb satisfied the lower band of the LTTAS requirement. During the entire period between 1962 and 1974, the Army continued with R&D efforts to improve its medium lift helicopter capability. These efforts included numerous studies and technical reports by schools, research corporations, and aircraft manufacturers which had a direct impact on the medium lift helicopter. In 1969, the Army initiated a two-phased program with Boeing-Vertol designed to allow the user and technical community to assess advanced transport helicopter capabilities and provide a sound basis for future military needs. This program resulted in the CH-47-347 proposal in late 1971 which far exceeded Army lift requirements and was subsequently rejected.

The advances in technology and concepts which could satisfy deficiencies could not be rejected and led to a sequential review, by the Army, of all technology which could be applied to the existing CH-47. This review began with 31 proposed modifications

and with some redirected R&D efforts was distilled to 15 and finally stabilized at 7 component/system changes. This effort resulted in the Concept Formulation Package which supports the CH-47 Modernization Program as opposed to a new procurement – the most cost effective means to sustain the Army's medium lift helicopter fleet. It was recommended that the entire fleet be modernized.

The CH-47 Modernization Program which was subsequently approved by the Army to sustain the MLH mission capability is primarily an engineering effort for the design and integration of seven (7) improved components or systems into the modernized aircraft. Table AM–G briefly describes each of these components and highlights some of the benefits derived from each. Figure AM–4 identifies the areas of systems improvements to be accomplished on the modernized fleet.

The CH-47 Modernization Program is an example of improving existing assets for maximum return on investment.

Component Improvements. Under the modernization plan the improved components/systems will be incorporated into a rehabilitated airframe configuration. A key element of the program is the capability of the older CH-47 airframes to continue to operate through the 1980s. The strength of the current CH-47 airframe was verified on the CH-47A. Airframe fatigue stresses were determined to have an unlimited life. The complete teardown and detailed inspection of three CH-47s after 2700 flight hours and up to four years of combat service further confirmed the integrity of the airframe as did the fact that no CH-47 accidents are attributable to airframe failure. For the CH-47 prototypes, the modification plan is to select and induct one each CH-47A, B and C model aircraft. Each of the three aircraft will be stripped of all electrical, hydraulic, and drive systems, cleaned and upgraded to the latest CH-47C configuration to which the improved components/systems will be added resulting in the YCH-47 prototype.

Propulsion System. The standard engine currently used in the CH-47A and CH-47B Chinook helicopters

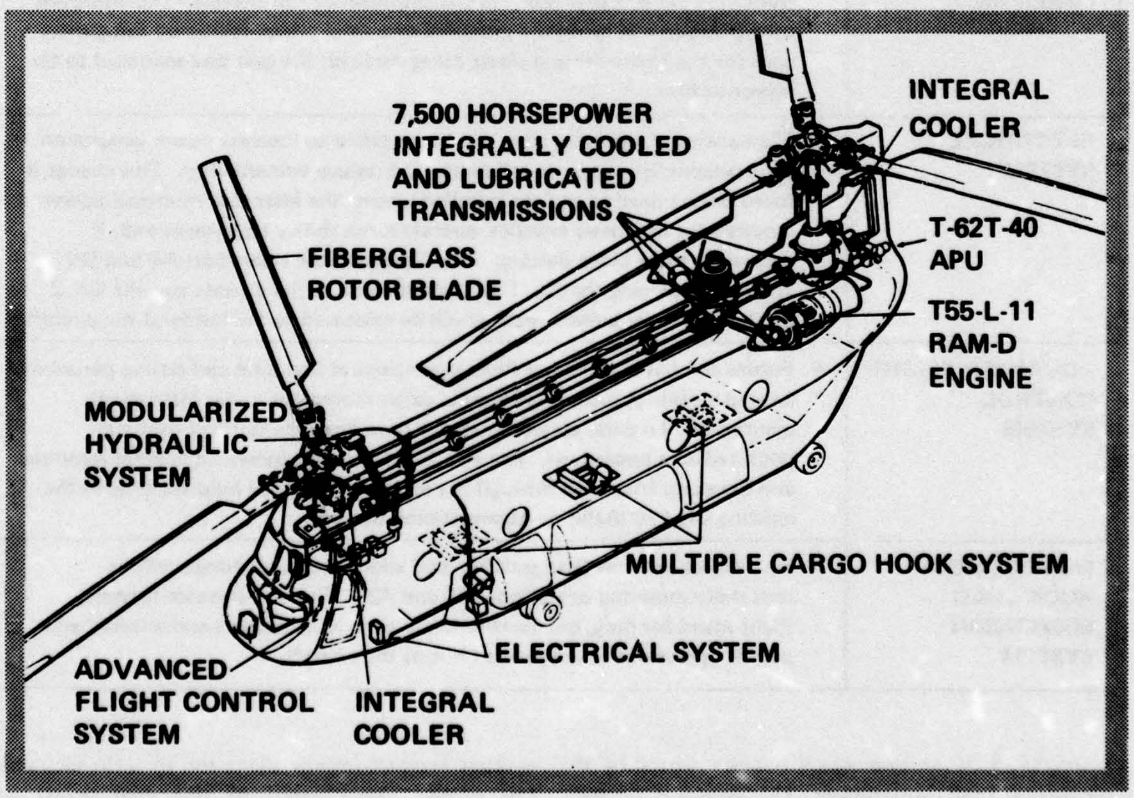


Figure AM–4. CH-47 Modernization improved systems.

TABLE AM–G
CH-47 MODERNIZATION COMPONENTS

FIBERGLASS ROTOR BLADE	• The new fiberglass rotor blade is a fail safe redundant structure with space for deicing capability; will be corrosion resistant, will have reduced vulnerability; and is expected to have a significantly improved service life. The fiberglass blade will provide a solution to every major problem existing with metal blades today.
TRANSMISSION/ DRIVE SYSTEM	• The CH-47 drive system will be redesigned to incorporate integral cooling and lubrication systems; better gear, bearing and case materials; and the 100% oil flow monitoring debris detection system. It will be uprated to 7500 horsepower. Reliability will be improved by increasing the size of internal components, and tuning the dynamic components. The system will be less vulnerable because of the elimination of cooling and lubrication lines on the forward, aft and combining transmissions.
HYDRAULIC SYSTEM	• The flight control and utility hydraulics systems will be modularized to: reduce lines, hoses and fittings; improve reliability; pressurized utility systems only when in use; integrate components; jam-proof the upper and lower flight control actuators; and provide minimum fluid leakage from remaining lines.
AUXILIARY POWER UNIT	• Auxiliary Power will be physically, electrically, and hydraulically separated from the auxiliary gear box and transmissions of the aircraft. The improved configuration will avoid the potential of a total power failure by using drive pads for the hydraulic and electrical systems on the gear box mounted to the power turbine.
ELECTRICAL SYSTEM	• The existing electrical system will be modified to increase power generation and transmission, improve reliability and reduce vulnerability. This change is based on the need to replace installed wiring, the increased electrical power required for improved avionics, aircraft survivability equipment and, if necessary, rotor blade deicing. It will separate the redundant AC and DC systems by placing the No. 1 on the right side of the aircraft and the No. 2 on the left. Wire bundle routing will be relocated to the inside of the aircraft.
ADVANCED FLIGHT CONTROL SYSTEM	• Future combat will require flight operations at low level and during period of limited visibility, including external cargo movement under instrument conditions. To date, several accidents have occurred during hover and confined-area operations. The AFCS, will provide increased control response and longterm trim hold through the addition of special hold features to the existing CH-47C Stability Augmentation System.
MULTI-CARGO HOOK LOAD SUSPENSION SYSTEM	• To increase external load stability two additional cargo hooks will be externally mounted at stations 260 and 420. This will increase forward flight speed for drag, low-density loads, such as containers and aircraft, and permit operations at the power limit of the aircraft.

is the T55-L-7C version which has the capability of producing 2850 horsepower. The demands of the Vietnam war introduced the requirement for a change in payload capability of the Chinook, resulting in another product improvement for both the airframe and engine. As a result of this dual thrust to improve the system, by the 1967-1968 timeframe, the T55-L11 series engine was developed to power the

CH-47C helicopter. The 3750 horsepower engine continues to be improved through the component improvement program (CIP).

Looking forward to the modernized Chinook, the current effort is to develop what is called the T55-L-712 engine. Development of this version of the T55 engine will be accomplished through modification programs and is a separate effort from the CH-47 RD&E development project. A new wide chord compressor blade configuration, the welded rotor, nozzles with improved cooling capability, an improved design T17 harness plus several other material changes will be included in the RAM-D engine. This engine is required and planned for conversion to coincide with the modernized CH-47 Chinook in the 1979-1980 timeframe. The progression of the T55 series engines component improvement program as presently planned is as follows:

- T55-L7C – Standard version for CH-47A and a temporary engine for limited CH-47B/C aircraft.
- T55-L11A – Standard version for CH-47C aircraft.
- T55-L11A/B – Includes shot-peened third stage turbine.
- T55-L11ASA – Includes welded rotor assembly.
- T55-L11D – Includes wide chord compressor blades.
- T55-L712 – Ultimate version for the modernized aircraft (formerly the RAM-D version).

Performance Objectives. The CH-47 Modernization Program is designed to increase the life of the older CH-47A, B and C aircraft while upgrading the performance of the A and B to meet the Required Operational Capability essential characteristics. The basic performance characteristics of the modernized aircraft are the same as the CH-47C in such areas as speed, endurance, number of troops carried, etc. Since it will retain its basic characteristics, there are few performance bands specified in the ROC, unlike development of a new/replacement aircraft alternative. The key performance goals are payload and reliability (see table AM–H for specific performance parameters). The payload is required to preserve medium lift transport capability for the support of engaged forces under environment conditions up to

TABLE AM–H
CH-47 MODERNIZATION PERFORMANCE PARAMETERS

PERFORMANCE PARAMETER	OBJECTIVE
PAYLOAD	• 16,050 lbs
RADIUS	• 30 NM
RATE-OF-CLIMB	• 200-500 fpm
MAINTAINABILITY	• 17.66 MMH/FH
RELIABILITY	–
SYSTEM OPERATIONAL	• 1.4 MTBF
HARDWARE SYSTEM	• 3.0 MTBF
MISSION	• 49.5 MTBF

4000 ft/95°F. Reliability is critical to provide for the required uninterrupted distribution of tactical equipment and supplies at FEBA.

Key Operational Capabilities. The following are the key operational capabilities that will be realized from the modernization system over the current systems:

- Improved capability to operate under night and adverse weather conditions.
- Provide for flight operations for low-level terrain flight tactics.
- Increased operational fleet lift capability of 15,000 lb at design conditions 4000 ft, 95°F, 30 nautical mile mission.
- Double productivity with outsize loads and multi-delivery capability.
- Stable external load transport.
- Improved stability and control in confined areas and other critical operations.
- Increased mission reliability through system and hardware reliability improvements. System operational reliability deals with the total malfunctions of an aircraft and is indicative of the actual maintenance hardware the aircraft imposes on the support environment. The hardware system reliability deals with the malfunctions attributable to the inherent design characteristics of a particular component.

Opportunity Areas. Looking at the total modernized aircraft in terms of indirect or noncosted returns, significant improvements are expected in the areas of reliability, availability, maintainability (RAM), safety, and vulnerability. Table AM–I shows a matrix which represents the areas of expected indirect returns of the systems to be modernized. The following specific benefits for the U.S. Army are predicted:

- Reliability – 15 percent reduction in maintenance failure rates from 1.04/hr to 0.88/hr.
- Availability – 4.50 percent increase in inherent availability – from 84.20 percent to 87.97 percent.
- Maintainability – 24 percent reduction in maintenance manhours per flight hour. Reduction from 23.18 to 17.66 MMH/FH for total direct productive field maintenance. Reduction from 14.22 MMH/FH to 10.83 MMH/FH aviation unit maintenance.
- Safety – 14 fewer aircraft lost (15 years of operation).
- Productivity – 13.9 percent (Mid-East) and 47.6 percent (Europe) increase in ton-NM day.
- Vulnerability – 36 percent to 75 percent reduction in vulnerable area, depending on type weapon.

In terms of direct investments, total life cycle cost savings (discounted) will be approximately $189.5 million. Using a 20-year retirement life, a constant fleet size and discounted dollars, a return on investment could be realized at the rate of 3.7 percent per year or 55.4 percent over a period of 15 years.

Other benefits to be derived from the Modernization Program include:

- Extension of fleet life.
- Standardized configuration of all CH-47s.
- Maximum parts standardization.
- Reduced direct operating costs in the field.
- Increased mean-time-removal for transmissions on rotor blades.
- Continuity of service support for Army ground forces due to the termination of the Heavy Lift Helicopter Program.
- Improved assistance to the Army in peacetime military commercial construction tasks, recovery of downed aircraft, disaster relief, shipment of containerized military cargo, etc.

Potential Problems. There are no major problems at this time and none are expected. Technical risks are considered low because:

- *The Modernization Program is applying available and proven technology resulting from previous development efforts with the advanced subsystems.*

TABLE AM–I
EXPECTED SYSTEM IMPROVEMENTS

BENEFIT	ROTOR BLADE	DRIVE SYSTEM	HYD SYSTEM	ELECT SYSTEM	MULTI-HOOK	AFCS	APU
RELIABILITY	●	●	●	●			●
AVAILABILITY	●	●	●	●			●
MAINTAINABILITY	●	●	●	●			●
SAFETY	●	●	●	●	●	●	●
VULNERABILITY	●	●	●	●			
PRODUCTIVITY	●	●			●	●	

- The rotor blade design is complete.
- Advance development design is underway for the hydraulic and transmission systems.
- The cargo suspension system is flight qualified.
- The advanced flight control system is production qualified and operational on the Canadian Chinook.
- Accelerated RAM testing will ensure early maturation of the modernized components.

Minor problem areas may result subsequent to contract award during the engineering development phase. Potential development and production problem areas will be addressed in the next annual update of this RDTE program if unexpected difficulties occur.

CURRENT AND PLANNED ACTIVITIES

In April 1975, the initial contract phase of the modification effort was initiated with a procurement contract which authorized Boeing-Vertol to proceed with the necessary analysis and advance engineering to design the transmission and hydraulic system. A separate engineering development contract with Boeing-Vertol is in effect for the development of the fiberglass rotor blades.

In August 1975, the CH-47 Modernization Program was presented to ASARC II and on 16 October 1975 it was placed before DSARC II. The ASARC and DSARC decisions recommended approval to the Deputy Secretary of Defense (DEPSECDEF) for the modernization of all models of the current CH-47 fleet. The Deputy Secretary of Defense reviewed the DSARC II recommendations and authorized the Army to proceed into full-scale engineering development, to develop one prototype each of the CH-47A, B and C models. Contractor's proposal for engineering development for the three prototype aircraft was received in October 1975. Target is to complete contract negotiations and award contract in late February 1976. This contract does not include production follow-on programs. After successful DT/OT testing of the prototypes, a LRIP contract will be awarded followed by a full-scale production contract award to modernize a total of 361 aircraft at the rate of three per month.

CARGO TRANSPORT MISSION SYSTEM

There are no cargo transport helicopter system development efforts under consideration by AVSCOM R&D at this time.

FUTURE MOBILITY SYSTEMS

UTILITY MISSION SYSTEM

Although there are no AVSCOM R&D efforts that directly relate to the future utility mission system, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed for a future utility system. A possible tilt-rotor configured utility aircraft is shown in figure AM–5. In addition, a Light Utility Helicopter (LUH) with performance and physical characteristics compatible with the ASH is also needed to assume many of the missions associated with mobility, combat service support, and command, control and communications. A description of the LUH is provided in table AM–J.

MEDIUM LIFT MISSION SYSTEM

There are no medium lift aircraft systems under consideration by AVSCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

CARGO TRANSPORT MISSION SYSTEM

General. The Heavy Lift Helicopter (HLH) will increase the surface mobility of ground combat forces by providing a means of crossing otherwise impassable barriers through quick emplacement of bridging, bringing in heavy equipment to remove an obstacle, or if required, by physically lifting the force over the barrier. Figure AM–6 shows various typical loads in the 0-35 ton range that an HLH would be required to airlift.

Two factors are significantly altering the Army's concept of logistical support. The first – and probably the most important – is the growing trend toward containerization. Projections indicate that the percentage of military cargo shipped overseas by containers will increase to 80 percent by 1982. Containerization offers the Army the opportunity to greatly increase the efficiency of its logistical system (supply, distribution and transportation).

The second factor that is changing the complexion of the logistics system is the increasing importance of recovery of battle-damaged equipment. Equipment is so expensive that the luxury of abandoning and replacing those items of equipment that sustain damage on the battlefield cannot be afforded. United States forces in Vietnam went part way in developing new doctrine in this area. Most repairable vehicles were recovered and rebuilt, and $3.8 billion worth of aircraft that were shot down during the conflict were

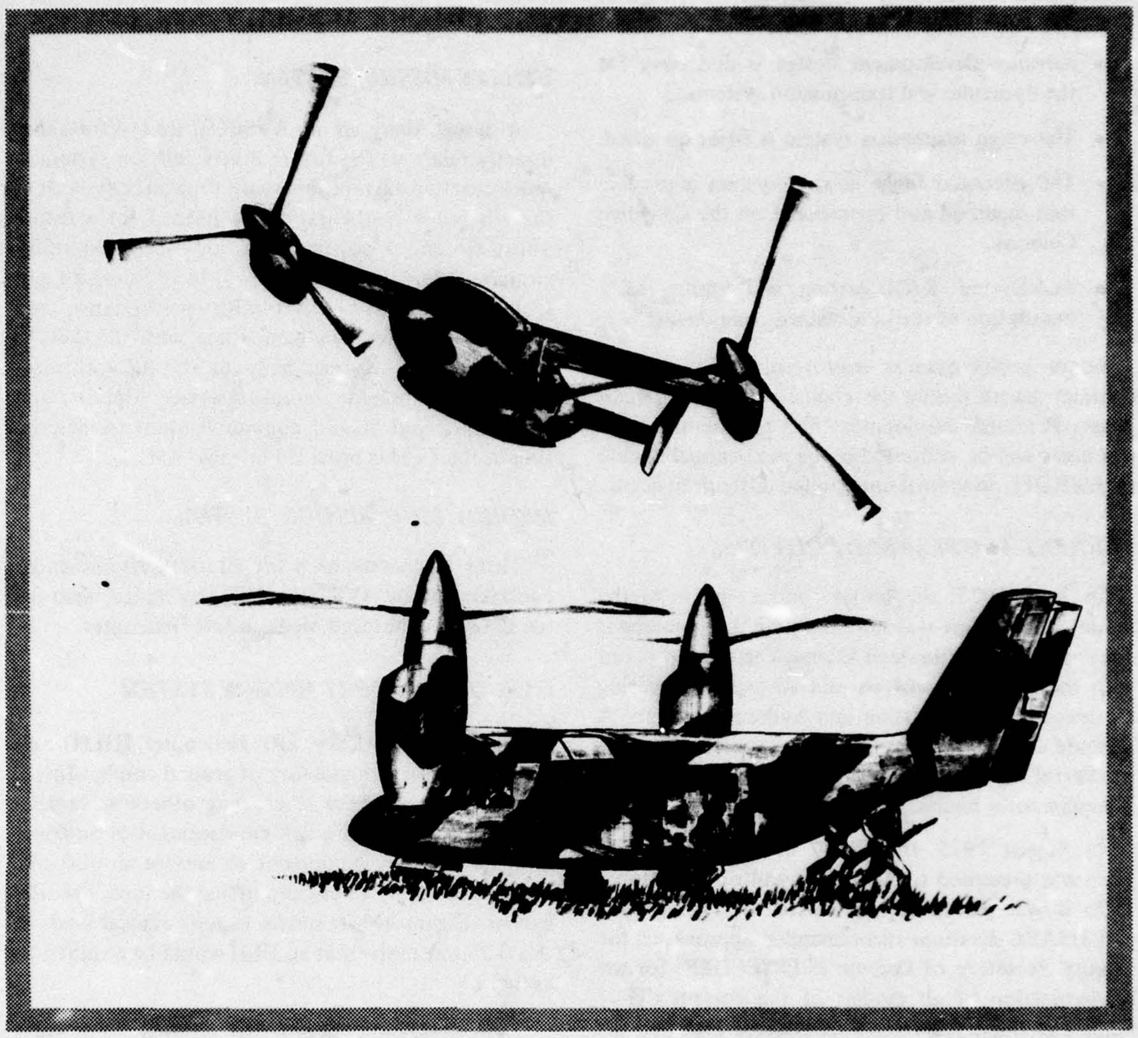


Figure AM–5. Possible tilt rotor version of future utility aircraft systems.

recovered and repaired. An HLH will greatly increase recovery and evacuation capability as it will be able to lift the great majority of the equipment used by the U.S. Armed Forces.

The HLH will be land based and is intended primarily as a logistics support vehicle, operating to the maximum feasible extent in rear areas. Its primary mission will include, but not necessarily be limited to, delivery and retrograde of containerized and unitized cargo, surface and aerial port clearance, unloading and loading container ships in a Logistics Over-The-Shore (LOTS) operation, and recovery and evacuation of damaged vehicles and aircraft. Additional missions for the HLH will be to provide airmobility to outsized and combat support equipment and provide support for military construction projects.

Vehicle Concept. The Trade-Off Determinations started with the HLH requirements as stated in the HLH Materiel Need. Several different concepts were examined for consideration in the trade-off determinations with the shaft-driven single rotor and tandem rotor concepts the only two concluded to be appropriate for further study. Technical examination of a total of 65 designs between the two concepts showed both the single and tandem rotor configurations to be feasible approaches to accomplishing the HLH mission. Analysis of the Integrated Logistics

TABLE AM–J
LIGHT UTILITY HELICOPTER DESCRIPTION

MISSION	• Troop lift. • Aeromedical evacuation. • Command and control. • Ground scout team insertion. • Infantry TOW team insertion. • Transport of external sling loads.
KEY PERFORMANCE FACTOR	• Troop lift – six combat troops. • Aeromedical evacuation – two litters, one ambulatory patient and one medical attendant. • Command and control – four staff members and command and control radio equipment. • Ground scout team – four combat troops with scout team equipment. • Infantry TOW team – four combat troops and infantry TOW team equipment. • Transport sling loads – acquire, transport, and release 2500 pound external load.
PERFORMANCE CHARACTERISTICS	• 120-150 knot airspeed. • 2.0 hour endurance. • 450 fpm VROC. • All weather capability.
PHYSICAL CHARACTERISTICS	• Same as Advanced Scout Helicopter (ASH).
SYSTEM APPLICATION	• The LUH, in conjunction with the LAH and ASH will replace the OH-6 and OH-58 as well as assume many of the present missions of the UH-1.

Support elements indicates that single or tandem configuration has little or no influence on support costs for the HLH and that, for the purpose of this study, these costs may be considered equal for both concepts. Likewise, in the Reliability-Availability-Maintainability (RAM) areas, there are no appreciable differences between the single and tandem rotor configurations for the HLH, and will consequently have no significant impact on the life cycle considerations. Life cycle costs vary enough, between the 65 designs examined, to make cost a factor in the selection of an HLH design. The subject of a single rotor vs. tandem rotor concept was addressed. In reviewing all the available data and considering areas such as costs, schedules, risk and other factors, the single rotor concept was determined to no longer be a cost effective approach. This then left the tandem rotor as the only viable and logical concept to pursue. The HLH as configured to demonstrate the advanced technology components of the system is shown in figure AM–7.

Considerable development efforts will be required for a HLH to be capable of transporting loads in the 50-ton range. For such a payload, configurations such as shaft-driven, hot cycle, or other gas reaction drive types must be considered. The total installed power would be on the order of 50,000 shp, with a transmission capable of transmitting more than 2.5×10^6 ft-lb of torque. Another configuration that deserves consideration is a hybrid lighter-than-air aircraft composed of balloon and helicopter elements. This configuration integrates the controllable thrust

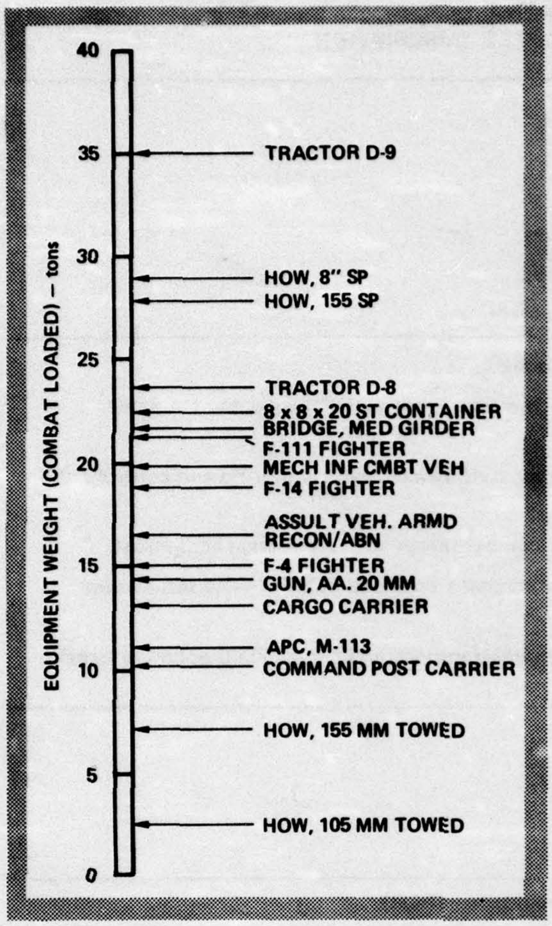


Figure AM–6. Payload capability of the HLH.

vector of a rotary wing system with the lifting capability of a heavy lift balloon. Aerostatic lift may support the full aircraft weight and up to 50 percent of the design sling load while aerodynamic lift supports only the remaining 50 percent of the sling load. Because the aerodynamic lift is not required to support the vehicle weight, the "square cube law," which plagues large helicopter design, is no longer applicable. A possible configuration concept is shown in figure AM–8.

In addition to adding to the deterrent capability of our general purpose forces, the HLH will have peacetime uses. It will be available to assist Government agencies with disaster relief in civilian communities and to provide support to the Nation's space effort. It is anticipated that there will be civilian applications for the HLH in the lumber and construction industries, as well as in the energy-related industries. An HLH should offer significant advantages to civilian industries involved in the construction and support of nuclear power plants, and petroleum acquisition and distribution facilities, particularly those offshore. In addition it may provide the only secure means of transporting the heavy (25 tons) recoverable cores of the many nuclear power plants that will be required to meet our energy requirements beyond 1980.

Salient Characteristics. The system description of a HLH capable of carrying 20-50 ton payloads is presented in table AM–K.

Opportunity Areas. The HLH could provide for the logistics and tactical movement of heavy outsized loads during the 1982-1995 timeframe if system development is initiated in FY77 or 78.

Potential Problems. All known-unknowns were addressed in the Advanced Technology Component phase of the HLH program and all areas of uncertainty have been reduced to the unknown-unknowns with the possible exception of production manufacturing. One of the objectives of tiedown and flight testing of the prototype would be to uncover any unknown-unknowns. Production manufacturing potential problems will be addressed if and when Engineering Development is authorized.

Planned Activity. Although the HLH program was terminated by Congressional direction on 26 September 1975, the Materiel Need Document dated 10 May 1972 (ACN 2958) remains valid. Assets required to complete the program have been temporarily stored, thus future HLH efforts are primarily dependent on funding constraints.

INTELLIGENCE

GENERAL

Army aviation performs this function in the role of the collecting and gathering of intelligence for the ground commander and for the acquisition and designation of targets for engagement by armed helicopters and other firepower means. The primary mission for this combat function is reconnaissance, surveillance, target acquisition and designation (RSTA/D). In addition, electronic warfare, decoy, and communication relay can be classified under this function although there is a definite overlap between intelligence and command, control and communications for some of the mission requirements.

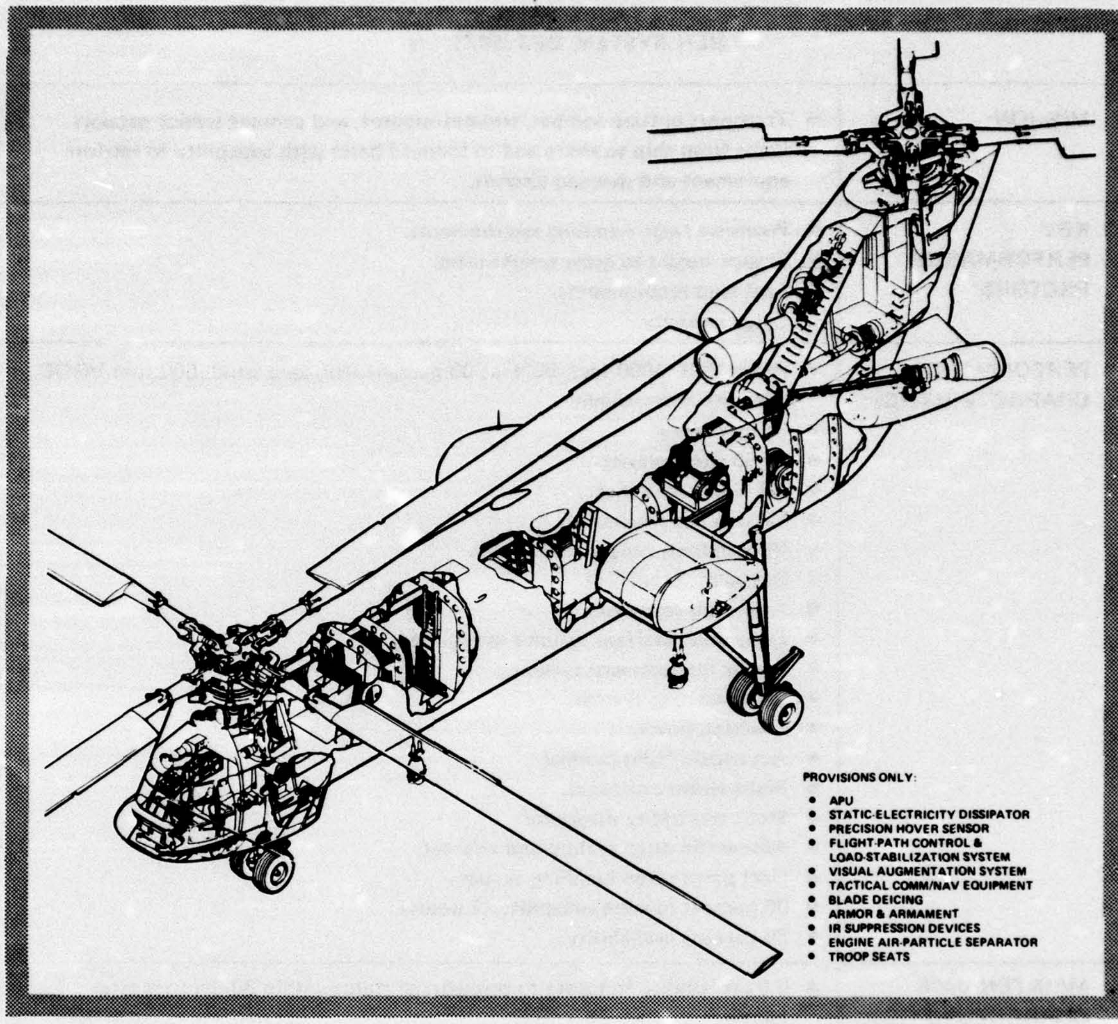
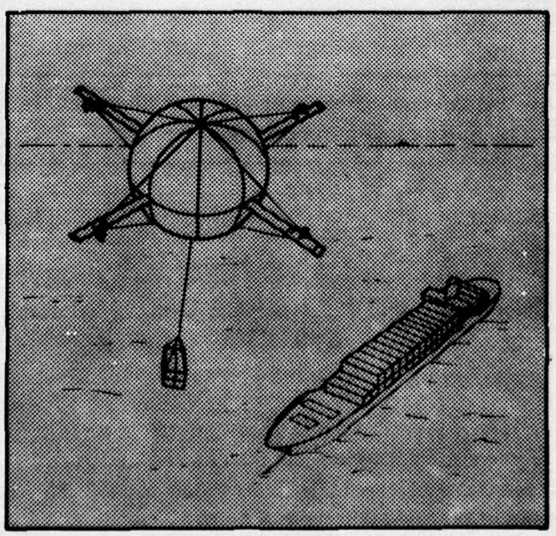


Figure AM–7. Advanced technology component projects of the HLH.



The key requirements for this function are good visibility, aircraft agility, simplicity, survivability, and ability to fly under conditions of reduced visibility and darkness. For the longer range intelligence gathering mission, the requirements are survivability, precise navigation, dash speed, and ability to carry sophisticated sensors providing real time readout of targets to ground stations.

Currently, this function is being performed by the OH-58 and OH-6 Light Observation Helicopters

Figure AM–8. Lighter-than-air cargo transport concept.

TABLE AM-K
HLH SYSTEM DESCRIPTION

MISSION:	• Transport outsize combat, combat support, and combat service support items from ship to shore and to forward bases with capability to retrieve equipment and downed aircraft.
KEY PERFORMANCE FACTORS:	• Precision cargo handling requirements. • Empty weight to gross weight ratio. • Fuel load requirements. • Cargo capacity.
PERFORMANCE CHARACTERISTICS:	• Hover OGE 4000 feet, 95°F at 95 percent IRP, zero wind, 500 fpm VROC, at design gross weight. • 3-6 man crew. • 20-50 ton payload. • 2-4 hour endurance. • Mission Subsystems • IR countermeasures as required. • Day-night capability • Anti-icing capability • Electronics warfare systems as required. • Traffic management system. • Fault warning system. • Precision hover. • Automatic flight control. • Night vision assistance. • Static electricity dissipator. • *Automatic cargo pickup and releases.* • Dual point cargo handling system. • 90 percent mission reliability (2 hours). • 80 percent availability.
MAINTENANCE CHARACTERISTICS:	• 0.9 probability to resore to operational status within 30 minutes after failure. • 300-hour periodic inspection. • 1200-1500 hours between overhaul. • 3000-4500 hour retirement life.
SYSTEM APPLICATION:	• There is no comparable existing aviation system in operation at this time although the CH-54 performs limited cargo transport functions.

(LOH) and for the stand-off mission, by the OV-1D Short Takeoff and Landing (STOL) airplane. The Advanced Scout Helicopter is currently in the planning stage to replace the LOH for this function and a draft LOA is being staffed for a replacement for the OV-1D. Remotely Piloted Vehicles (RPV) are being developed to perform this function for operation in the high threat environment.

CURRENT INTELLIGENCE OPERATIONAL SYSTEMS

RSTA/D

The current RSTA/D Army aircraft are the light observation helicopter and the observation aircraft. A discussion of the LOH is presented in table AM–L and of the OV-1D in table AM–M.

TABLE AM–L
CURRENT LOH DESCRIPTION

GENERAL	• This aircraft is used in visual reconnaissance, aerial scouting, and command and control functions by brigade and lower units. The current aircraft are the Bell OH-58A and Hughes OH-6.
PRESENT CAPABILITIES	• For unarmed observation missions, the OH-58A has a 260-mile range, or 3.0 hr endurance at a takeoff gross weight of 2,760 lb. Armed with the XM-27EI weapon system and 2,000 rounds of ammunition, it can perform an armed scout mission with a range of 230 miles, take-off gross weight of 2,767 lb, with a subsequent reduction of endurance. It is light, agile, relatively easy to fly and maintain, and has good all-around visibility.
DEFICIENCIES AND SHORTCOMINGS	• The LOH is restricted to day and night visual and marginal visual flight conditions. It lacks navigational radios, instrumentation, and yaw stability for flight under instrument meteorological conditions (IMC). In the aerial scout role, its power and performance are inadequate. It has a distinctive noise signature, and needs improvements to lower its radar and IR signatures. It lacks vision-enhancing equipment; thus, target acquisition depends entirely on the ability to recognize the target, locate it by map coordinates, and transfer this information to the weapon crew.
FOLLOW-ON SYSTEM	• A product improvement program is being planned for the OH-58 to permit flight under instrument meteorological conditions and improved performance. For the aerial scout mission, the Advanced Scout Helicopter (ASH) is in the planning stage as the follow-on system. For the high throat environment, the LOH is programmed to be replaced by the RPV.

TABLE AM–M
CURRENT OBSERVATION AIRCRAFT DESCRIPTION

GENERAL	• The 0V-1D STOL airplane is the current Army observation aircraft.
PRESENT CAPABILITIES	• The 0V-1D is capable of performing either IR reconnaissance or side-looking airborne radar (SLAR) missions. The SLAR and IR pods are interchangeable, providing quick-change mission adaptability. The aircraft can perform photographic and visual reconnaissance missions, has a 180-knot cruise speed, and an endurance of just under 2 hr. With external fuel tanks, it can be ferried more than 1,100 nautical miles. It has good short-field performance and can be operated from unimproved runways or dirt fields.
DEFICIENCIES AND SHORTCOMINGS	• Because of its mission and method of employment, the survivability of the 0V-1D is inadequate. It lacks adequate antiradar and antiinfrared electronic countermeasures. It lacks terrain-avoidance equipment for nap-of-the-earth flight. A higher dash speed is required for increased survivability during mission accomplishment. In addition, a greater endurance is required to increase mission payoff. Greater reliability of both the aircraft and avionics sensor package would be highly desirable.
FOLLOW-ON SYSTEM	• The 0V-1D is programmed to be replaced by the 0V-X.

DEVELOPING INTELLIGENCE SYSTEMS

ADVANCED SCOUT HELICOPTER

General. The Advanced Scout Helicopter (ASH) will be a light, highly survivable helicopter dedicated to conducting reconnaissance, aerial observation, security and target acquisition/designation functions, day and night, in all intensities of conflict. In performing these roles, the ASH will operate in air cavalry, attack helicopter and field artillery units. It will be able to detect, identify, and locate targets at standoff ranges using nap-of-the-earth tactics. It will be able to remain on station for extended periods and have an accurate navigation system for precise target location. The design is to be optimized for maximum stability and maneuverability during hovering flight and during NOE flight.

Operational/Organization Concepts. The Advanced Scout Helicopter will operate as a part of a scout/attack helicopter team. The primary units to be equipped with the ASH are attack helicopter, air cavalry, and field artillery units. The helicopter will be used primarily for reconnaissance, security, aerial observation, and target acquisition missions. Threat weapons in the forward battle area will require that these missions be conducted at standoff ranges and at nap-of-the-earth altitudes for increased survivability.

The ASH must be capable of communication with all Army ground units, other Army aerial vehicles, and other aerial and ground based attack systems. Additionally, the ASH will remain on station for extended periods of time, monitoring enemy movement, controlling combat forces and participating in poststrike analysis.

The Advanced Scout Helicopter will be required to perform throughout the range of environmental and climatic categories where U.S. forces can be expected to operate while being exposed to the entire spectrum of threat formations and weapons normally encountered in the forward battle area (i.e., individual weapons, crew-served automatic weapons, automatic weapons on armored vehicles, AA weapons, and certain surface-to-air missiles).

System Characteristics. A partial listing of the ASH system characteristics are presented in table AM–N. A complete listing of the characteristics are contained in the Classified Annex to the Plan.

Performance Characteristics. See Classified Annex to the Plan for a listing of the ASH performance characteristics.

Vehicle Concepts. A concept of the ASH is shown in figure AM–9 where a conventional helicopter is depicted. The conventional helicopter provides for good, low-speed capability and good maneuverability at low forward speed. If rotors with hub moment capability are employed, then good agility to meet nap-of-the-earth flight can be achieved readily. The pure helicopter, however, becomes limited if high agility is required at higher flight speeds.

REMOTELY PILOTED VEHICLES

System Discussion. The potential of unmanned, remotely piloted vehicles for military application is practically unlimited. Extensive efforts on RPVs have been underway for many years, covering a wide range of applications and missions. It is only recently, however, that both the need and the technological capability for RPVs have coalesced to the point that the development of these systems has become imperative.

The primary driving force behind the present Army program is the highly sophisticated threat posed to any airmobile system used in a modern battlefield, as well as the danger a forward observer/designator faces in a modern battlefield. The threats to aircraft performing surveillance, reconnaissance, target acquisition, damage assessment and similar roles have increased markedly because of the existing and projected ground-to-air guided missiles, as well as the multimode acquisition and tracking quad-23 antiaircraft gun system. The high threat posed by these weapons tends to deny airspace to the Army and severely limit its ability to obtain battlefield information as well as its ability to locate and designate targets precisely. Such limitations could adversely affect the operations of the battlefield commanders.

One logical counter to this threat is the use of small unmanned air vehicles (mini-RPV), designed to operate at the lowest cost possible. By reducing the observables (visual, acoustic, IR emission, and radar cross section) such mini-RPVs could penetrate sufficiently close to selected areas within and beyond the FEBA to be effective. Sensors, cameras, and designators can be mounted on the RPVs, which can be used to transmit real-time information for surveillance and target acquisition, perform reconnaissance, and designate targets. Without a man in the aircraft, the size

TABLE AM–N
ASH SYSTEM CHARACTERISTICS

ESSENTIAL CHARACTERISTICS	• The ASH system shall provide reconnaissance, security, target acquisition and precision designation functions during day and night VMC and perform limited reconnaissance and security functions during IMC. • Aircraft performance and flight handling characteristics criteria specified for the Advanced Scout Helicopter will be compatible with the requirements for the AAH and UTTAS aircraft systems. • A flight crew of two is required, pilot and copilot/observer. The aircraft will be donfigured so that one pilot can perform all duties while flying the aircraft, but dual flight controls are required. • Ballistic protection is required.
AVIONICS	• As a minimum, the Advanced Scout Helicopter will have installed the basic flight instruments required for instrument flight as specified by AR 95-1. • Provisions for an airspeed indicator capable of accurately measuring and portraying airspeeds compatible with operational requirements. • Provisions for an absolute altimeter are required. • A low-level, tactical navigation system is required. • If available within the timeframe, the aircraft should have provision for communications that will enable continuous, secure non-line-of-sight communications.
VISIONICS	• A target acquisition subsystem is required. • A pilot's night vision subsystem is required to provide the pilot a capability to conduct nap-of-the-earth night operations.
TARGET LOCATION/ DESIGNATION	• A target designation subsystem with rangefinder and target location subsystem is required.
RELIABILITY AND MAINTAINABILITY	• Built-In-Test-Equipment (BITE) shall be incorporated to identify malfunction of specific modules and subsystems and to accomplish "on aircraft" maintenance.
WEAPON SYSTEM	• Space, weight, and power shall be provided for the installation of a three (3) round missile system.
SURVIVABILITY EQUIPMENT	• State-of-the-art countermeasure protection against visual, aural, infrared and electronic systems will be incorporated in the design of the ASH.

*Unclassified Listing.

and cost of the aircraft can be reduced, and missions can be performed in very high threat environments without concern as to the possible loss of life of the aircrew. If the cost can be made low enough, the RPVs may be considered expendable.

The predecessor programs to the present Army mini-RPV work consisted of a series of exploratory tests of mini-RPVs conducted under the sponsorship of DARPA. In these studies, model airplane radio control technology was applied and growth versions were constructed and tested. It was shown to be technically feasible to operate motion picture cameras, transmit TV pictures, and designate from small aircraft (wingspans of 10 to 15 ft, speeds up to 100 mph). Following this work, the Army (ECOM)

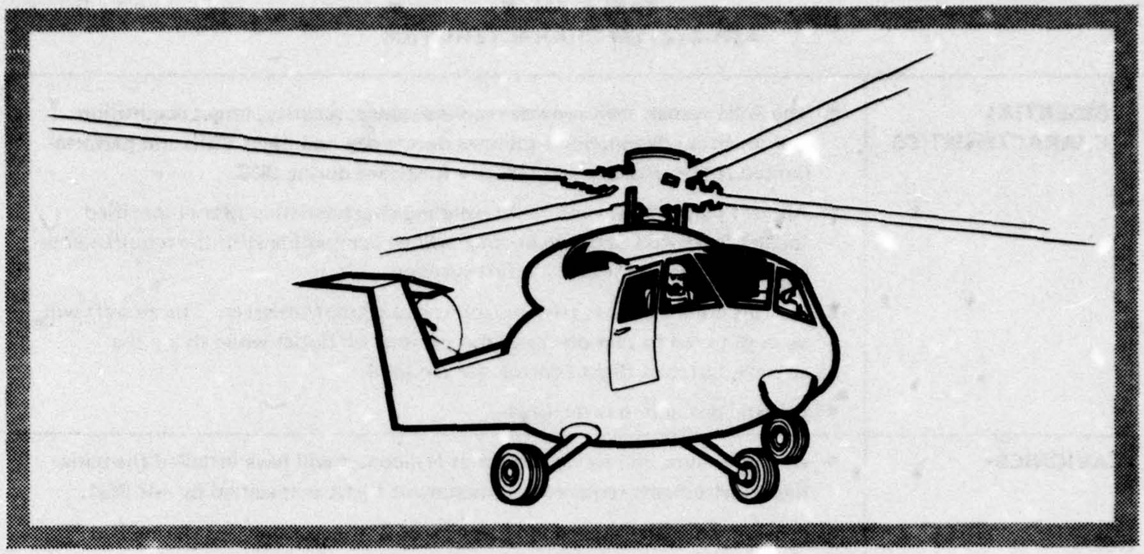


Figure AM–9. Possible helicopter concept of ASH.

with DARPA support conducted the RPAODS (Remotely Piloted Aerial Observation/Designation System) program. That program explored the low cost mini-RPV approach in more depth. A series of available aircraft were procured, as well as a range of small, light-weight sensors. Testing was accomplished at an RPV test range set up at Ft. Huachuca, Arizona. Studies on the vulnerability, data link, and sensor capability were conducted. The overall results tended to verify the earlier conclusions that mini-RPV could perform several of the surveillance and target acquisition roles.

On the larger scale, the U.S. Air Force has had a broad-ranging RPV program, which has included the large Firebee-type drones, the large Compass Cope high-altitude, long-duration system, as well as work funded by DARPA in the mini-RPV area such as the Lockheed AEQUARE.

Other high-performance RPV systems besides the Firebee include modifications to the Northrop MQM-74, the Belgian Epervier, and the Canadian AN/USD-501. All of these high-speed drones are, or can be, configured to carry out some of the missions discussed. Their cost may be higher, loiter time lower, and observables higher. Derivatives of such drones could be useful for selected missions.

The range of possible aircraft systems to fulfill the need for a low-cost RPV includes modifications to existing large drones, through modified model airplane technology. Possible avenues include fixed-wing aircraft, helicopters, and various VTOL concepts. Figures AM–10 and AM–11 depict possible helicopter and VTOL configurations. The history of drones has shown that the recovery of the aircraft is a most difficult problem. Earlier Army experience with the SD–1 to SD–5 drones indicated a very low mission completion rate, primarily because of recovery problems (mainly crash damage). Likewise, the Air Force did not get good effectiveness from their drones until they went to the Mid-Air Recovery System (MARS). In the MARS system, a parachute is released at flight termination, and a helicopter snatches the parachute and lowers the RPV to the ground. Thus, because of the troubled recovery history, many of the possible aircraft systems will emphasize the recovery phase of the system.

Another technological gap (and, hence, technological challenge) is the absence of a secure data link capable of sending real-time or near-real-time video information, as well as target, vehicle status, and navigation information. The propulsion for the RPVs is critical because no engine developments have been undertaken for mini-RPVs and total dependency has been placed on using engines derived from commercial engines such as "Go-Kart" or modified model airplane engines. In the slightly larger categories of RPVs, the loiter time is a direct function of the type of propulsion used. If loiter time is to be increased, then propulsion changes will be necessary.

The method of field operation of RPVs by battlefield units is unknown. Except for the SD–1 through

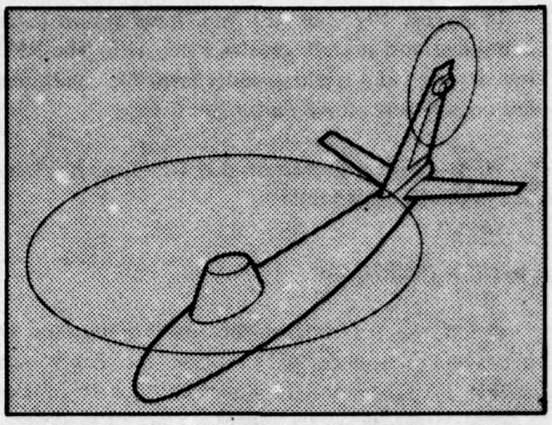


Figure AM–10. Helicopter type RPV.

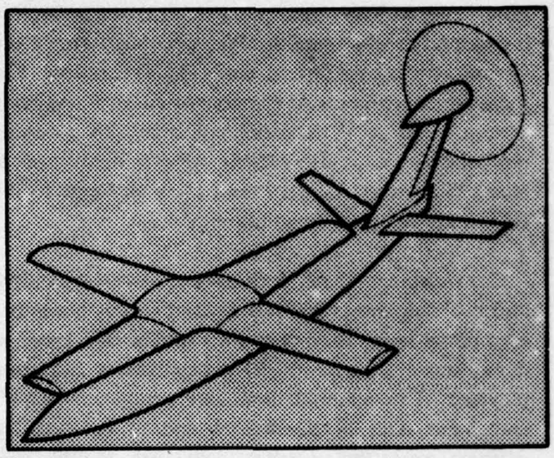


Figure AM–11. A stopped rotor VTOL version of a high speed RPV.

SD–5 drone series, the Army has little experience in operating RPVs under field conditions. The best philosophy for integrating aircraft, ground control, launch and retrieval, support, training and maintenance procedures are, as yet, undetermined. A means for controlling several RPVs simultaneously must also be established before full exploitation of RPVs can be assured. The need to operate at night and under a wide range of weather conditions poses a whole host of technical questions, including effects on recovery, the navigation system, and the onboard sensors.

The primary missions for the RPVs appear, at this time, to be those related to information and designation. These roles include reconnaissance, surveillance, target location and identification, target coordination determination, and target designation. Such missions will ultimately need to be carried out under night and all-weather flight conditions.

Other potential missions include target destruction by Kamikaze tactics, jamming, decoys of all types, damage assessment, mapping, mine and REMBASS placement, and chaff, leaflet or chemical dispensing.

In many cases, a given RPV will be expected to handle a variety of these missions. Because of the diversity in missions, however, the needs for payload, duration, response time, and agility may require a few distinct sizes and types of RPVs to cover the spectrum adequately.

Because the Army had only limited field use of RPVs (other than target drones from selected U.S. Army bases, and no battlefield experience with them). AVSCOM found it necessary to invoke a unique user-developer operating relationship in the development and procurement of RPVs. To meet this challenge, and to try to exploit the earliest possible use of RPV technology, the Army assigned the management of RPVs to a single point, AVSCOM, which established the RPV-WSM, in February 1974.

In the case of the higher speed artillery aerial surveillance, close interaction between the needs of the user and the development/modification and procurement has been carried out in the classical fashion.

In the case of the mini-RPV, which has a potentially broad role, the classical pattern was changed. Here, the user is actively involved not only in setting up broad requirements for a system considered feasible for near-term employment but also in helping to establish the goals for the R&D program itself. To this end, the mini-RPV program of the Army will provide for a series of technology demonstration RPV systems. These systems will represent steps in increasing technological difficulty, while offering increased capability to the user. As each technology demonstrator evolves, the user will participate in hands-on testing to determine not only its operating characteristics, but also what it will do for him, its potential impact on field operations, including tactical, as well as skill levels of people and logistics. The primary benefit will be early user evaluation of a concept, and a shortened feedback cycle between user and developer. The inherent risk of this management approach – that of putting developmental hardware into the field – and the possible problems that will arise will be carefully watched at all levels of management within the Army.

Three potential technical problems that apply to all RPV systems are indicated here. More specific problems are indicated in subsequent sections. The critical problems are:

- Secure data link
- Engines and propulsion
- Recovery

The discussion here will be limited to the secure data link, since the latter two items are discussed under the AQUILA program in the next section.

The secure data link is considered the most critical technological problem in the deployment of RPVs in a combat environment. The ability to control the vehicles and to receive the data back is vital to the success of the RPV concept. If the systems are jammed, the RPVs are useless. Such systems must be compatible with the military communications network and must fit into the overall frequency allocation system. Because the secure system for TV require considerable bandwidth, they pose special problems on frequency allocation. The frequencies that may be available are expected to be in the J-band. However, at high frequencies (10-15 GHz) it may be difficult to develop the solid-state amplifiers planned for present mini-RPV systems. Since small size, low weight, low power, and reliability are all predicated on solid-state LSI techniques, the whole concept of secure data links in J-band may present a formidable problem.

One use of RPVs was demonstrated on 3 October 1975 when an RPV was used as an airborne laser platform to designate a tank during the CLGP (Cannon Launched Guided Projectile) demonstration. One laser guided artillery round was fired and scored a direct hit on an M-48 tank at a range of 8 miles.

In September and October 1975, MASSTER (now TRADOC Combined Arms Test Activity) conducted simulated RPV missions by mounting a Westinghouse Blue Spot TV sensor system in a U-1A (Otter) aircraft and flying reconnaissance missions during field exercises of an Armored Division. The entire operation was directed from a ground station based upon the information displayed on a video monitor in the ground station. Effective detection, recognition and tracking of trucks, tanks, helicopters, and other vehicles resulted.

In August 1975, an RPV was flown against radar controlled anti-aircraft guns at Eglin AFB. The RPV was detected and tracking under favorable conditions but no hits were scored during live firing.

These events demonstrate that RPVs can be effective in their assigned roles.

AQUILA PROGRAM

Description of System. Because of the lack of hands-on experience with RPVs, the Army was unable to write an ROC document nor to initiate normal, full-scale development of an RPV system. The combat developer not only needed experience operating the RPV but also a better understanding of how a full RPV system operated. This understanding is essential for the combat developer to determine the Organizational and Operational (O&O) concepts. The material developer had experimented with available experimental RPV hardware and analyzed potential performance, but also lacked RPV systems experience. This experience is essential as an input to the ROC and Concept Formulation Package.

To overcome these deficiencies, a new technique and program was conceived, whereby a small number of representative RPV systems would be developed to demonstrate a range of RPV capabilities and complexities. The material developer would gain experience and data in developing and procuring RPV systems and the combat developer would gain hands-on experience with representative RPV systems. The system operational characteristics were based upon an informal letter requirement (little "r") rather than a formal approved ROC (big "R"). To keep costs reasonable, technical characteristics were based upon current state-of-the-art; commercial off-the-shelf technology and hardware were used whenever feasible. Selected operational characteristics for this program, now called AQUILA (Latin for eagle), are:

- Launch and recovery in an unimproved area
- Range 15 to 20 km
- Minimum man-in-loop
- Map plotting board
- Real-time display
- Instant replay
- Video recorder

- Preprogrammable flight paths
- Operator override

The military designation XMQM–105 has been assigned to the AQUILA mini-RPV.

The AQUILA RPV System Technology Demonstrator (STD) consists of an RPV, Ground Control Station (GCS), launcher, recovery system and associated ground support equipment. The RPV is an all-wing design 6 ft long with a wing span of 12.35 ft with an 11 hp single cylinder "go-kart" engine driving a pusher propeller as shown in figure AM–12. Interchangeable payloads are mounted in the nose. The structure is made of Kevlar to obtain low weight and low radar reflectivity.

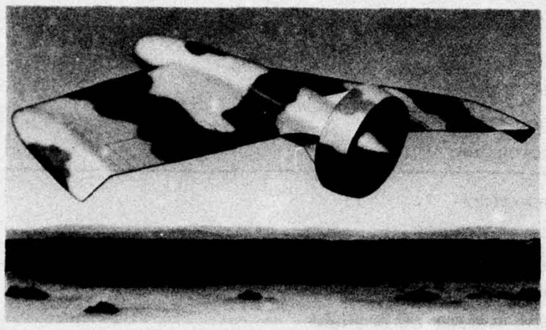


Figure AM–12. AQUILA RPV.

Control is exercised via data link from a GCS housed in a modified S-280 mobile shelter. The GCS contains separate video monitors and control panels for the RPV operator and the sensor operator, a computer, position plotters, radar antenna, and appropriate controls and displays. The data link provides for transmission of the TV video signal to the GCS, a command and control uplink, and telemetry down-link. An onboard autopilot system and GCS provide preprogrammable flight path control, operator override and correction capability in both visual and non-visual line of sight operation.

The RPV is launched from truck or field mounted pneumatic catapult launcher. It is recovered by engaging an arresting cable with a hook deployed from the RPV and falling into a horizontal net. The RPV is guided to the arresting cable by monitoring the glide path via a TV camera and making manual course corrections.

The overall system is illustrated in figure AM–13. Salient characteristics are summarized in table AM–O.

The AQUILA program was formulated in five phases corresponding to five different sensor packages. These progress from a relatively simple unstabilized TV sensor to more complex systems which include a panoramic camera, stabilized TV and

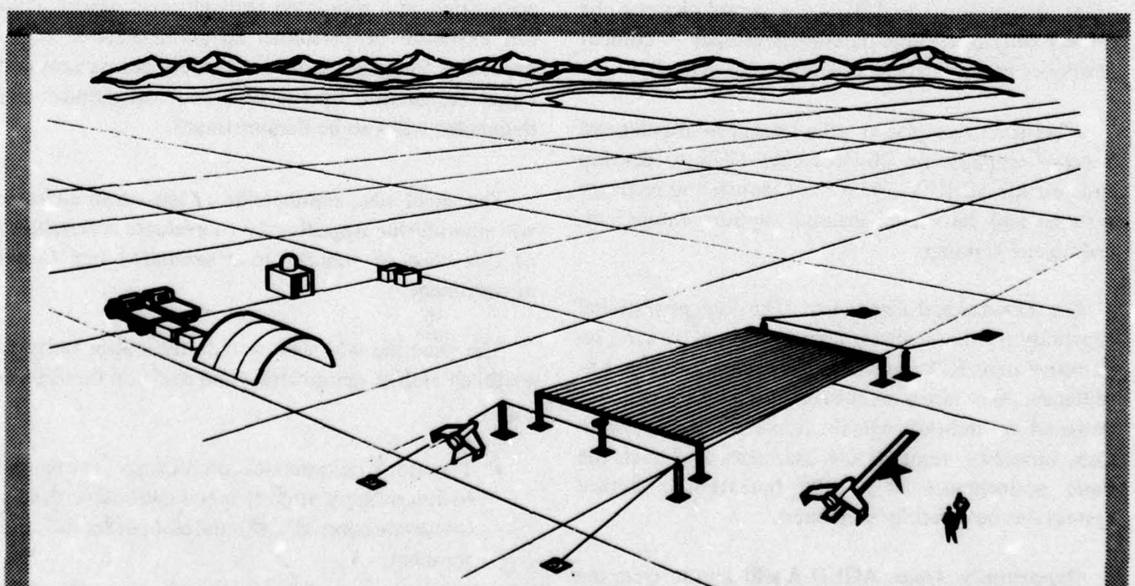


Figure AM–13. AQUILA system.

TABLE AM–O
SALIENT CHARACTERISTICS OF AQUILA

MISSION	• **To demonstrate capability of a small, unmanned, remotely piloted aerial vehicle system to find, identify, locate, designate (with laser), and adjust artillery fire on enemy targets.**
KEY PERFORMANCE PERFORMANCE FACTOR	• **Within cost and time constraints, to demonstrate RPV system technology realistically.**
PERFORMANCE CHARACTERISTICS	• **Cruise (band): 50 to 105 kt** • **Gross wt. (max): 130 lb** • **Payload (min): 30 lb** • **Endurance (min): 1.5 hr** • **Service ceiling: 12,000 ft MSL** • **Time to 10,000 ft: 20 min** • **Minimum observables** • **Stable autopilot** • **Winds: 20 kt, gust to 35 kt** • **Take off 4,000 ft, 95°F** • **Common launch and recovery system** • **Common ground control system**
MAINTENANCE CHARACTERISTICS	• **Unit maintenance by operators** • **Support maintenance by contractor** • **Modular removal/replacement** • **Pre-launch go/no-go checkout** • **15 launches per RPV with average 1.0 hr flight**

a laser designator. The AQUILA program phases to be carried out in a joint materiel developer – combat developer program are outlined in table AM–P.

A contract was placed with Lockheed Missiles and Space Company on 20 December 1974 to develop and provide 30 RPVs, 4 GCSs, 4 launch and recovery systems and associated ground support equipment, testing and training.

Key Operational Capability. The key operational capability is the realistic demonstration of a representative mini-RPV system in the reconnaissance, surveillance, and target acquisition role. Although not designed to military specifications of shock, vibration, humidity, temperature extremes, and dust, the basic performance of a fully operational, tactical system can be carefully simulated.

Opportunity Areas. AQUILA will demonstrate the abilities of an unmanned aircraft system to provide real-time TV (or near-real-time photographic hardcopy) for reconnaissance, surveillance, and target acquisition in a simulated tactical environment without exposure of personnel to antiaircraft fire. The capability for target location, artillery adjustment and target designation by use of a laser rangefinder and designator will also be demonstrated.

The small size, nonmetallic construction airframe will provide the opportunity to evaluate survivability of this class of vehicles in a simulated high-threat environment.

The program will also provide the opportunity to establish and/or demonstrate and evaluate the following:

- The use of commercial components (as opposed to full military aircraft specifications) with realistic evaluation in a simulated operational environment.
- Maximum use of autopilot and preprogrammed flight as compared to man-in-the-loop operation.

TABLE AM–P
AQUILA PROGRAM PHASES

PHASE I – TV SURVEILLANCE	**• One (1) ground station with:** **Position display or plotting board compatible with 1:50,000 and 1:100,000 scale tactical maps.** **Air data and condition displays.** **Auto pilot override.** **• Ten (10) aircraft with eight (8) sensor systems with:** **Common airframe and engine.** **Interchangeable sensor subsystem.** **Unstabilized, steerable TV.** **Adjustable field of view.** **• One (1) launch and recovery subsystem with minimum length launch and recovery.** **• Minimum GSE and system checkout.**
PHASE II – PHOTO RECONNAISSANCE	**• Five (5) aircraft with four (4) sensor systems all identical to Phase I with addition of a 35 mm panoramic camera.**
PHASE III – TARGET ACQUISITION	**• Five (5) aircraft with four (4) sensor systems, all identical to Phase I except TV is stabilized to 0.05 mrad rms.**
PHASE IV – TARGET LOCATION/ ARTILLERY ADJUSTMENT	**• Five (5) aircraft with four (4) sensor systems, all identical to Phase III with the addition of a laser rangefinder and computer in the ground control station to determine target location within 100 meters CEP.**
PHASE V – LASER DESIGNATION	**• Five (5) aircraft with four (4) sensor systems identical to Phase IV. Laser designator compatible with terminally guided weapons.**

- Techniques for launch and recovery in unimproved areas.
- Use of a way point, ground track navigation system.
- Target location and RPV control by an Analytical Photogrammetrical Position System (APPS) in a side-by-side experiment.
- Required military operator skill levels using Army hands-on operation.
- Realistic statistics and projections of RPV reliability and maintainability (RAM) requirements.

Potential Problems. Flight testing began 1 December 1975. Initial problems have been typical developmental problems which were corrected by changes in detail design or operating techniques. There are potential problems of a broader nature which past RPV experience indicates may develop for later RPVs.

The currently available engines were developed for commercial ground applications. They are heavy and noisy, have high vibration levels and fuel consumption, lack auxiliary power drives and have not been proven in flight operations. A significant 6.2 effort has been initiated to evaluate and modify such engines and to develop associated propellers, fuel systems, mufflers and generator/alternators.

All past RPV recovery systems have been beset with problems. Parachute recovery increases weight, size and complexity of the RPV and has high risk of damage. The helicopter aerial recovery technique is complex and costly in addition to requiring dedicated recovery aircraft. Net recovery techniques have had only limited success. The arresting hook technique, being used in the AQUILA STD Program is complex and may not be operationally suitable for Army

applications. A comparative study of recovery techniques and tests of a back-up recovery system will be initiated this fiscal year.

Data link performance and reliability has been a problem in earlier RPV programs. Data link operation is dependent on line-of-site contact and location and performance of the antennas as well as the reliability of the equipment. Some difficulties were encountered in early AQUILA testing which have been corrected by detail design changes. Until more extensive experience has been obtained, there is concern about the data link performance. In addition, the data link is subject to jamming or capture. Techniques are available to prevent jamming and capture and separate development is being conducted to apply these techniques to mini-RPVs.

Survivability is a major concern. Small radar, visual, aural and infrared signatures are inherent in a mini-RPV and good design practice will minimize these signatures. Such minimization and evaluation has been left for development in parallel with the AQUILA program. A test at Eglin AFB, mentioned in an earlier paragraph, provided encouragement that the RPV can survive in a hostile environment. The Kevlar type structure used in AQUILA is expected to be able to accept hits with only localized damage.

Reliability in the classical sense is of no unusual concern in that state-of-the-art components and techniques are used to a large degree even though the application is new. Adequate system testing should result in a reliable system.

Potential problems exist because of the possibility of overall growth in weight, complexity, and cost of the RPV system as the development program progresses. Most air vehicle development programs show such trends. In the case of the mini-RPV where low weight, complexity and cost are essential to its employment, avoidance of such growth is crucial to its success.

CURRENT AND PLANNED ACTIVITIES

The Contract with Lockheed Missiles and Space Company for the design, development, testing and maintenance of the AQUILA RPV System Technology Demonstrator and training of Army personnel is in its second year. The contract will provide 30 RPVs, 25 sensor packages, 4 ground control stations, 4 launchers, 4 recovery systems and associated support equipment. Flight testing began on 1 December 1975. After three months of joint DARCOM-Contractor design validation testing the Phase I, RPV system will be provided to TRADOC for hands-on evaluation. Phases II through V, as described earlier, follow at 2, 2, 1 and 1 month intervals respectively.

Successful completion of the AQUILA program will lead to the preparation of a ROC to be submitted to DA for approval in October 1977. Full scale development would then be initiated leading to an IOC in late 1980 or early 1981 for a tactical system designated Little Scout.

Remaining AQUILA assets are planned to be used to provide airborne platforms to demonstrate advanced hardware and missions. These include day-night and all-weather capability, anti-jam data link, multi-RPV control, jammer, relay, and alternate recovery concepts. This portion of the program is called Little "r" II. A supporting technology program is described in later chapters.

A schedule for AQUILA and the Little Scout programs is shown in table AM–Q.

TABLE AM–Q
SCHEDULE OF RPV ACTIVITIES

1st Flight of AQUILA	1 Dec 75
1st TV Surveillance RPV delivered to AMC	Mar 76
First Deliveries to TRADOC	
Phase I Unstabilized TV	May 76
Phase II Unstabilized TV/Radio	Jul 76
Phase III Stabilized TV	Sep 76
Phase IV Tgt Loc/Arty Adj	Oct 76
Phase V Tgt Designation	Nov 76
Complete AQUILA System Tech Demo	Dec 76
Approved ROC for Little Scout	Aug 77
IPR/ASARC II	Oct 77
Initiate Engineering Development	May 78
IPR/ASARC III	Mar 80
Initiate Production	Dec 80
IOC	Feb 81

FUTURE INTELLIGENCE SYSTEMS

RSTA/D

General. A system is required to provide the battlefield commander with timely, essential intelligence information in real or near-real time. The system must include a single multipurpose airborne platform which can carry the sensor systems to perform the roles of surveillance, reconnaissance, target acquisition and electronic warfare. The platform must be capable of multisensor employment without requiring a ground change of modules. It must be data-linked to the ground and operate in instrument meteorological conditions.

OV-X. The OV-X platform is a tactical aircraft designed to provide a platform for the various intelligence collection/electronic warfare systems. The platform will be organic to the Aerial Exploitation Battalion, Combat Electronic Warfare Intelligence Group (Corps) and will operate from unimproved tactical airfields within the corps. It will loiter at various altitudes in a standoff profile up to 50 km on the friendly side of the line of contact (depending on the air defense threat). Knowledge of accurate platform location and heading will be provided to the aircraft crew and appropriate ground station. The sensor equipped OV-X will directly interface with complementary intelligence and target acquisition systems and provide the sensor derived product (by data link) to subscribers located throughout the corps area.

The platform will replace 10 models of aircraft (three OV-1 and seven RU-21) currently used to perform RSTA and EW roles. A valid requirement exists for an OV-X platform. A draft LOA is presently being staffed to cover the development of the OV-X platform.

To meet the operational employment concept, the OV-X platform design should address the following capabilities and characteristics:

- Operational ceiling of 25,000 ft MSL with aircraft pressurization.
- Sensor payload up to 4,200 lb and 360 ft^3 compartment volume, exclusive of cockpit.
- Endurance of 5.0 to 8.0 hr mission time.
- Ferry range capable of worldwide self-deployment.
- Tactical, high accuracy navigation system to support the mission equipment package.
- Terrain avoidance system capable of providing ample crew warning to allow avoidance of obstacles during night and limited visibility conditions.
- Aircraft survivability technology should be considered in the aircraft design.
- Aircraft avionics should include a flight director system, autopilot, weather radar and full instrumentation for IMC.
- Aircraft should have sufficient fuselage and wing ground clearance for all external antennas.
- Aircraft should have an auxiliary power source capable of providing 30 KVA independent of propulsion system.
- Aircraft to be capable of having an environmental control system for the mission equipment of 60,000 Btu cooling.
- The system must possess sufficient RAM to be effective and supportable in the field. Detailed RAM requirements will be developed during the advanced development effort.

Surveillance VTOL Aircraft. The OV-X platform will only provide standoff mission capability operating from a fixed site. For penetration missions, VTOL capability will become a prime requirement. A candidate configuration for a manned VTOL platform is the tilt-rotor concept. A system description of a Surveillance VTOL Aircraft System (SUR/VTOL) is presented in table AM–R.

FIREPOWER

GENERAL

The firepower function as used herein includes two mission definitions. One is to destroy or disrupt enemy armor and mechanized forces by aerial firepower and the other is to provide tactical mobility and support air assault or airmobile operations throughout the battle area.

TABLE AM–R
SURVEILLANCE VTOL AIRCRAFT SYSTEM DESCRIPTION

MISSION	• Provide immediate and continuing intelligence and target acquisition intelligence to the tactical ground commander with penetration capability.
KEY PERFORMANCE FACTORS	• Endurance. • VTOL capability.
PERFORMANCE CHARACTERISTICS	• 150-400 knot airspeed capability. • 2-3 man crew. • Agile. • Signature Minimum radar cross-section image. Minimum visual contrast profile for anticipated environment. • Self-deployable. • Mission subsystems Multispectral sensors. Stabilized electronics platform. Data link, data processing and storage. • All weather operation. • Self-contained navigation. • Unattended remote area landing system.
PHYSICAL CHARACTERISTICS	• Transportable by air or ship or self-ferry. • Accessible configuration for ground support equipment.
MAINTENANCE CHARACTERISTICS	• Built-in test equipment. • Modular replacement of components. • 0.9 probability to restore to operational status within 30 minutes after failure. • On-condition replacement of critical components. • 1 MMH/FH (scheduled) and 7.5 MMH/FH (unscheduled).
SYSTEM APPLICATION	• VTOL surveillance aircraft would replace the LOH for penetration mission requirements and supplement the OV-X with VTOL capabilities.

Currently, Army aviation provides firepower via the AH-1G Cobra armed helicopter. Greater capability, particularly in the antitank role, will be provided by the AH-1Q (Cobra-TOW) as an interim system. Key factors are the discriminating nature of direct aerial fire support to be close in, highly responsive, and available in all-weather and at night. The Advanced Attack Helicopter (AAH) provides increased firepower, flexibility, all-weather operation, and increased survivability aspects over the current systems. The UH-1 has in the past been used to provide the Army with tactical mobility capability.

CURRENT FIREPOWER SYSTEMS

AH-1G

The current Army attack helicopter (armed) is the AH-1G. A discussion of the Cobra is provided in table AM–S.

TABLE AM–S
CURRENT ATTACK HELICOPTER DESCRIPTION

GENERAL	• The current firepower system in Army aviation is the Bell AH-1G Cobra.
PRESENT CAPABILITIES	• The AH-1G uses UH-1 engine and drive components, together with a reduced frontal cross-sectional area and tandum seating. It has a diverse mix of armaments, including the 7.62 mm minigun, a 40 mm grenade launcher, and 2.75 inch folding fin aerial rockets. The gunner uses simple sighting and ranging. The AH-1G has an endurance of 2.5 hr and can operate at speeds up to 140 knots. It is highly maneuverable and possesses a stability and control augmentation system.
DEFICIENCIES AND SHORTCOMINGS	• The AH-1G has marginal mission payload capability and performance at higher density altitudes. It does not have an effective antiarmor weapon system or the growth potential to accept more sophisticated weapons. It lacks adequate target designation, precise navigation, and precise range and sighting equipment. It does not have night vision devices and is inadequate for IFR flight. Although its speed is adequate for the mission, its agility and maneuverability at the higher speeds are inadequate.
FOLLOW-ON SYSTEM	• The AH-1 will be replaced by the AAH for the armed helicopter system.

DEVELOPING FIREPOWER SYSTEMS

ADVANCED ATTACK HELICOPTER

Description of System. The Advanced Attack Helicopter (AAH) is assigned the role of providing direct aerial fire in support of the combined arms team in land combat operations. It can be based closer to the FEBA, thus providing a faster response time, and can operate at lower ceilings than a fixed-wing aircraft, thus providing a higher percentage of battlefield day employment. The AAH also can provide more sustained firing time during an engagement because of its hovering capability and nap-of-the-earth performance. (See figure AM–14 for a representation of the AAH system.)

The firepower of the AAH will be used in conjunction with, and in support of, the firepower provided by the field artillery, tanks, armored personnel carriers, and infantry weapons of the combined arms team. The objective of the AAH is to provide quick response, highly accurate firepower to support ground operations during day, night, and marginal weather. The importance attached to the firepower function and mission of the AAH is aptly signified by its designation as one of the five highest priority projects among all Army development projects.

The AAH is a twin-engine rotary-wing aircraft functioning as a stable, manned aerial weapons system capable of delivering accurate missile, rocket, and automatic weapon fire to point and area targets. The AAH is required to perform its assigned missions of direct aerial fire under day, night and marginal weather conditions (0.5 mile visibility, 200-ft ceiling). Low cost is a principal objective of the program. The Army intends to develop an effective AAH at the lowest possible operating acquisition cost. Each contractor's design considers operating cost, production cost, and performance. The Army has established a range of \$1.4 to \$1.6 million as the recurring flyaway cost. Major emphasis is placed on cost reduction through critical examination of operational characteristics, improved producibility, and innovative production techniques.

Primary Mission. Typical profiles for the AAH primary mission of supplying direct aerial fire as an integral part of the land combat force are classified CONFIDENTIAL and are presented in the Classified Annex to the Plan.

Ferry Mission. Ferry missions (auxiliary fuel tanks permitted) require a range of 800-1000 nautical miles against a 20-knot headwind. A 45-min fuel reserve at maximum range speed will be provided for flights up

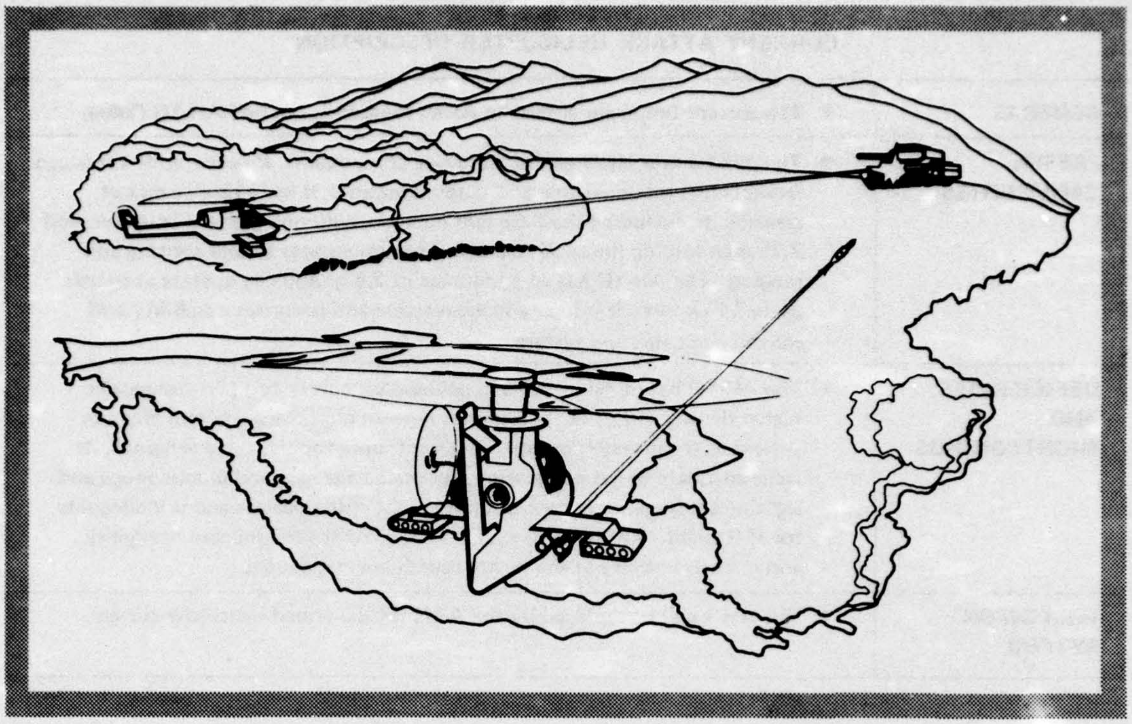


Figure AM–14. Advanced Attack Helicopter system.

to 3 hr in length. For flights over 3 hr, reserve will be increased by 10 percent of the additional fuel at the airspeed and headwind required above. Two minutes at maximum continuous power will be allowed for warmup and takeoff. The mission will be performed at standard day conditions with takeoff at sea level.

Roles and Missions. The roles and missions of the AAH are presented in table AM–T.

Performance Characteristics. The AAH major performance characteristics are delineated in table AM–U.

Mission Reliability. The following discussion defines the mission reliability requirements listed in table AM–U:

- The aircraft will be designed to have a mission reliability of not less than 0.95 based on 1 hr of mission time. Mission reliability is defined as the probability of completing a mission and landing at a predetermined area without an equipment malfunction or failure that precludes successful completion of the mission, given that the equipment was operationally ready at the start of the mission. The stated aircraft mission reliability requirements include all Government furnished property (GFP) but does not include the area weapon subsystem, 2.75-inch FFAR, point target weapon subsystem and the HELLFIRE Modular Missile System (HMMS). The AAH has a separate reliability for the area weapon subsystem as a probability of fireout of 0.92 to 0.94 for a 1000 round complement.

- The system reliability will be 0.70 based on 1 hr of mission time. System reliability is defined as the probability that the AAH system (less expendable ordnance) while performing its specified function under intended flight conditions will incur no failures that require unscheduled maintenance.

- The MTBR of aircraft major dynamic components will be not less than 1500 flight hours for both scheduled and unscheduled removals.

- The MTTR as defined per MIL–STD–721B for Aviation Unit Maintenance Support maintenance will be 0.65 to 0.90 hr.

TABLE AM–T
AAH ROLES AND MISSIONS

PROVIDE	• Antiarmor/strike-force capability. • Other hardpoint target capability. • Standoff antitank capability. • Antipersonnel capability. • Area antiarmor/antimaterial capability. • LZ preparation and support during airmobile assault. • Additional fire support to airmobile movements. • Discriminating fire support for all offensive and defensive operations in built-up area, (i.e., combat in cities). • Target identification and handoff. • Aerial escort during movement of forces to include airmobile operation, long range patrol, insertion/extraction escort, medical evaluation/resupply escort, and convoy protection. • Suppressive fires during assault landings and extractions. • Augmentation and extended range of other fire support means.
CONDUCT	• Armed reconnaissance. • Economy of force operations. • Screening, flank, and covering force operations. • Rear area security operations.

- The MMH/FH for Aviation Unit Maintenance and Intermediate Support Maintenance will be 8.0 to 13.0 hr. The MMH/FH for depot-level maintenance will be not more than 6.5 to 10.7 hr. These requirements are direct productive maintenance requirements as defined in TM38–750–1 and include subsystems.

Physical Characteristics. Principal subsystem physical characteristics are shown in table AM–V.

Night vision requirements are classified CONFIDENTIAL and are presented in the Classified Annex to the Plan.

Configuration. The Bell Helicopter Textron version of the AAH is shown in figure AM–15 and the Hughes Helicopter Company version is shown in figure AM–16.

Key Operational Capability. The key operational capability desired in the AAH is the disruption and destruction of enemy armor formations. This task includes attack of enemy tanks, other armored vehicles, deployed troop formations both mounted and dismounted, assembly areas, command posts, and forward logistic complexes.

Opportunity Areas. The discussion on this subject contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

Potential Problems. The discussion on this subject contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

Current and Planned Activities. Requests for proposals (RFPs) were issued to the principal helicopter manufacturers on 15 Nov 72. Proposals were received on 15 Feb 73 and source selections were announced on 22 June 73. Development go-ahead from the Deputy Secretary of Defense was announced on 19 July 73. Bell Helicopter Textron and the Hughes Helicopter Company were awarded competitive development contracts under which they will build two

TABLE AM–U
AAH PERFORMANCE CHARACTERISTICS

KEY PERFORMANCE FACTORS	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• Hover OGE at 4000 feet 95°F, VROC 450-500 fpm at 95 percent intermediate power, zero wind 145-175 KTAS cruise speed at 4000 feet, 95°F using not more than maximum continous power. • Endurance of not less than 1.9 hours at 4000 feet, 95°F based on: 8 minutes at maximum continuous power 38 minutes at 80-100 KTAS at DGW with mission stores 6 minutes of cruise speed at DGW 32 minutes HOGE at DGW 30 minutes reserve at maximum range speed, at DGW minus expendable ordnance and fuel consumed in above conditions • 800-1000 nautical mile ferry range against 20-knot headwind (auxiliary tanks permitted). • IR suppression. • Marginal weather day and night mission capability.
MAINTENANCE	• 300 hours between inspections. • 1,500 hours MTBR for aircraft major dynamic components. • 0.65-0.90 hours MTTR per MIL-STD-721B. • 8.0-13.0 MMH/FH AUM and ISM. • 6.5-10.7 MMH/FH for depot.
MISSION RELIABILITY	• Mission reliability of 0.95 for 1 hour. • Area weapon subsystem reliability of a probablity of fireout of 0.92 to 0.94 for a 1000 round complement. • System reliability of 0.70 for 1 hour.

flying prototypes and one ground test vehicle. Selection of one contractor for full-scale development including subsystems will be accomplished in the first quarter of FY77.

The development schedule with associated milestone descriptions and long-range planning program synopsis are classified CONFIDENTIAL and are presented in the Classified Annex to the Plan.

FUTURE FIREPOWER SYSTEMS

GENERAL

The employment of Army aviation units in a high threat environment will have the greatest impact on the attack helicopter in meeting the Army aviation objective of providing the commander with the mobility, firepower, and staying power needed to win the first battle. Increased emphasis must be placed on survivability, particularly through terrain flying techniques. However, other system requirements such as dash speed and endurance must not be overlooked.

AERIAL ATTACK SYSTEM

R&D efforts are necessary to continue technological improvements in the systems key performance factors. Advancements in weapons, sensors, propulsion, aerodynamics, and structures as well as tactics may well lend to the AAH being behind the state-of-the-art in the early 1990s. One postulated R&D planning concept for the replacement of the

TABLE AM–V
AAH PHYSICAL CHARACTERISTICS

WEAPONS SYSTEM	• **Point Target Subsystem** This primary subsystem will be used to defeat armor and other point type targets. The HELLFIRE Modular Missile System is required for the copilot/gunner with a day and night capability using the Target Acquisition and Designation System (TADS). • **Area Weapon Subsystem.** The Area Weapon Subsystem will consist of a flexible turret mounting a 30 mm automatic weapon. The 30 mm dual purpose HEDP round has not been combat tested but its design has been optimized for light armor point targets. • **Aerial Rocket Subsystem** This subsystem will provide rocket fire with the 2.75-inch FFAR. The subsystem will provide in-flight selectivity of various warheads and fusing options. The subsystem will be integrated into the external stores subsystem and fire control subsystem. The 2.75-inch rockets have been employed in combat in an armor defeating role. The newly developed heat warhead is effective against armor and can also be used for antipersonnel.
FIRE CONTROL SYSTEM	• The fire control subsystem will be a totally integrated subsystem consisting of the TADS, air data sensors, aircraft attitude and velocity sensors, pilot and copilot helmet sights, fire control computer, and all associated controls and displays necessary for the delivery of firepower. The HH HMMS is being concurrently developed as the point target system for the AAH. The stabilization and control accuracy of the TADS will be consistent with performance requirements necessary for autonomous designation of point targets for the laser HELLFIRE missile. The day/night range requirements for TADS are classified CONFIDENTIAL.
EXTERNAL STORES	• Four external stores stations will be provided. Each will be capable of missile and rocket stores carriage and operation, and be equipped to provide in-flight elevation and depression. Each station will be capable of carrying auxiliary fuel stores if required to meet ferry mission requirements.
CREWSTATION ARMOR	• **Seat Armor** Armor protected seats are required for both crewmembers. The seats must provide maximum protection for the head, neck, and torso area of the aircrewman's body (exclusive of the chest area and forward hemisphere) against 12.7 mm AP with an impact velocity of 1600 fps and zero degrees obliquity. • **Airframe Armor** Armor is considered only as a last resort after all methods of passive defense have been considered. For the 12.7 mm API and 23 mm HEI threats, redundancy, damage tolerance and vulnerability reduction design features contribute to a high degree of vulnerability reduction; whereas armor contributes to a smaller degree of vulnerability reduction and is used only in areas where damage tolerance cannot be achieved. Transparent armor of sufficient strength to defeat the fragmentation and survive the blast of an exploding 23 mm HEI will be placed between the crewmembers to preclude incapacitation of both crewmen from a single projectile. Nontransparent armor may be used as a barrier between crewmembers in those areas not affecting the aft crewman's external vision envelope.

TABLE AM–V (Continued)

MAIN ROTOR GROUP	• Blade Construction. Blades will be individually interchangeable. The design will provide for erosion protection, limited operation at treetop level (with ensuing strikes by small branches within confined areas without catastrophic blade damage) and minimal probability of a catastrophic failure after a hit by a 23 mm HEI projectile. • Blade Tracking and Balance. Tracking and balancing techniques will be simple and will eliminate the need for test flights after tracking, balancing, and blade folding.
NAVIGATION SYSTEM	• The navigation system will be doppler without map display. The system will provide continuous digital readout in UTM and Lat/Long coordinates.
SURVIVABILITY	• Infrared suppression will be engineered into the system by reducing surface emissivity of the engine group. A removable kit-type IR emission will be provided for the engines. • Sealf-sealing, crashworthy fuel cells will be provided.
TRANSPORTABILITY	• The AAH shall be transportable in a C-141 and C-5A.

Figure AM–15. Bell Helicopter Textron version of AAH.

AAH is the Advanced Aerial Weapons System (AAWS). This vehicle would most likely be a multi-engine aircraft with VTOL capability for operation in and out of forward bases. To attain the desired dash speeds, conversion to an airplane type operation is indicated. Possible aircraft concepts include augmented thrust helicopter, tilt rotor, tilt wing, and deflected thrust. Possible weapons include advanced

Figure AM–16. Hughes Helicopter Company version of AAH.

fire-and-forget missiles, antimissile missile, and air-to-air weapons. The AAWS system description is presented in table AM–W and a possible tilt rotor configuration of the AAWS is shown in figure AM–17.

TACTICAL MOBILITY

To provide a complete combined arms team, R&D planning efforts should include a Light Attack Helicopter (LAH) to supplement the AAH by providing economical armed reconnaissance and fire support to small combat units. A LAH system description is presented in table AM–X.

COMBAT SERVICE SUPPORT

GENERAL

This function involves the traditional combat service support function of providing an airline of communication capable of delivering supplies from a rear storage area to the immediate vicinity of the user. The "retail" delivery of high priority cargo to the company and platoon areas is accomplished by utility helicopters, while cargo helicopters (CH-47, CH-54) particularly advantageous when port and transport perform the "wholesale" bulk delivery of high priority cargo. Relatively short distances are involved, but within inhospitable environment and terrain. Fixed bases are generally not available; hence, VTOL capability is a requirement. In this respect, the prime mission of the HLH will be the delivery of containerized cargo from offshore positions, across the beach, and to forward supply areas. This capability is facilities are either inadequate or not available. In addition, the recovery of damaged equipment or captured enemy material can be accomplished by the larger cargo helicopters. For transport of supplies to the forward area in a high threat environment, a system capable of carrying external loads in nap-of-the-earth flight profiles and in day-night all-weather condition is required. In addition, the cargo handling subsystem should be as automated as possible to eliminate ground handling crews.

CURRENT COMBAT SERVICE SUPPORT SYSTEMS

UTILITY MISSION SYSTEM

The current standard Army aircraft performing the utility mission of the combat service support function

TABLE AM–W
ADVANCED AERIAL WEAPONS SYSTEM DESCRIPTION

MISSION	• Provide area and point target suppression/kill capability. • Offer security and escort to troop carrying helicopters. • Provide extended area reconnaissance.
KEY PERFORMANCE FACTOR	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• 250-400 knot airspeed capability. • All-weather operational capability. • Self-deployable. • 3-hour endurance at cruise speed. • Auxiliary power unit augments lift/thrust. • Self-contained navigation.
PHYSICAL CHARACTERISTICS	• Transportable in C-5A. • Self sealing fuel tanks.
MAINTENANCE CHARACTERISTICS	• 300-hour periodic inspection. • On-condition replacement of critical components.
SYSTEM APPLICATION	• The AAWS would be a replacement for the Advanced Attack Helicopter currently being developed.

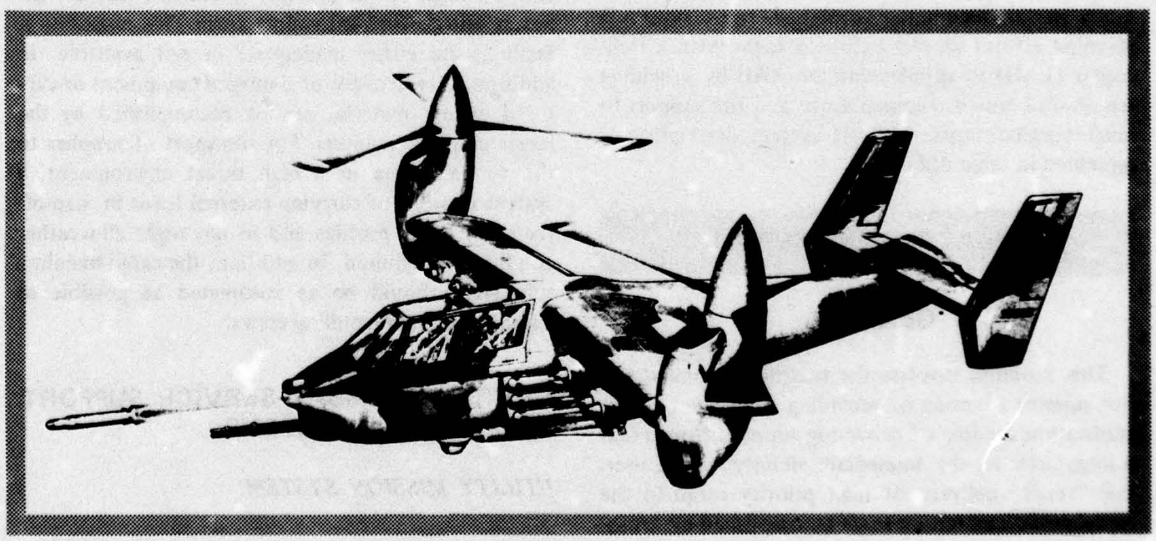


Figure AM–17. Tilt rotor version of AAWS.

TABLE AM–X
LIGHT ATTACK HELICOPTER DESCRIPTION

MISSION	• Armed reconnaissance. • Area suppression and point target destruction.
KEY PERFORMANCE FACTOR	• Ability to acquire and destroy targets. • Survivability.
PERFORMANCE CHARACTERISTICS	• 120-150 knot airspeed. • 2.0 hour endurance. • 450 fpm VROC. • All weather capability.
PHYSICAL CHARACTERISTICS	• Same as Advanced Scout Helicopter (ASH)
ARMAMENT	• 7.62 flexible machine gun. • Missile System consisting of: HELLFIRE Modular Missile System (four rounds); or TOW Missile System (four rounds); or Laser Beamrider Missile System (four rounds).
SYSTEM APPLICATION:	• The LAH, in conjunction with the ASH and the LUH, will replace the OH-6 and the OH-58. • The LAH will supplement the AAH by providing economical armed reconnaissance and fire support to small combat units.

is the UH-1 helicopter. A discussion of the UH-1H is presented in table AM–A.

MEDIUM LIFT MISSION SYSTEM

The CH-47C is the current Army medium lift helicopter. A discussion of the CH-47C is provided in table AM–B.

CARGO TRANSPORT MISSION SYSTEM.

The CH-54B is the current Army cargo transport helicopter. A discussion of the CH-54B is presented in table AM–C.

DEVELOPING COMBAT SERVICE SUPPORT SYSTEMS

UTILITY MISSION SYSTEM

The UTTAS, which is under development, will fulfill the utility mission of the combat service support function. However, usage and mission equipment will vary as the need dictates. See pages AM–2 through AM–11 for a discussion of the UTTAS.

MEDIUM LIFT MISSION SYSTEM

The follow-on system for the current CH-47 fleet will be the CH-47 Modernized Medium Lift Helicopter. See pages AM–9 through AM–15 for a discussion of the CH-47(D).

CARGO TRANSPORT MISSION SYSTEM

There are no cargo transport helicopter system development efforts under consideration by AVSCOM R&D at this time.

FUTURE COMBAT SERVICE SUPPORT SYSTEMS

UTILITY MISSION SYSTEM

Although there are no AVSCOM R&D efforts that directly relate to a future utility mission for the

combat service support function, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed. In addition, a Light Utility Helicopter with performance and physical characteristics compatible with the ASH is also needed to assume many of the missions associated with mobility, combat service support, and command, control and communication. A description of the LUH is provided in table AM–J.

MEDIUM LIFT MISSION SYSTEM

There are no medium lift aircraft systems under consideration by AVSCOM R&D as a replacement for the CH-47 Modernized Medium Lift Helicopter.

CARGO TRANSPORT MISSION SYSTEM

The Heavy Lift Helicopter concept is needed to satisfy future cargo transport mission, associated with the combat service support functions. See pages AM–15 through AM–18 for a discussion of the HLH.

COMMAND, CONTROL AND COMMUNICATIONS

GENERAL

The function of command, control and communication is made more challenging by the far-ranging operations envisioned for an expanded battlefield. Rapid movements and immediate response are required to supervise a widely dispersed operation. Currently performed by LOH and UH-1 aircraft, this capability for future operations should be expanded down to the company level. The UTTAS and improved version of the LUH are projected to perform this role for the battalion and higher commanders while the company level operation requires a simple, small NOE Mini-Manned Aircraft System (MMAS) capable of hovering and transporting specialized troops.

CURRENT COMMAND, CONTROL AND COMMUNICATION SYSTEMS

AVIATION SUPPORT

The current Army aircraft providing support to the field commander are the LOH and UH-1. A discussion of the LOH is presented in table AM–L and the UH-1H is presented in table AM–A.

DEVELOPING COMMAND, CONTROL AND COMMUNICATION SYSTEMS

AVIATION SUPPORT

The UTTAS, which is under development, will perform the aviation support mission of the command, control and communications functions for the battalion commander and higher echelon levels. See pages AM–2 through AM–11 for a discussion of the UTTAS.

FUTURE COMMAND, CONTROL AND COMMUNICATION SYSTEMS

AVIATION SUPPORT

UTTAS. Although there are no AVSCOM R&D efforts that directly relate to a replacement aircraft for the UTTAS, a quick reaction/high productivity type aircraft, such as the tilt rotor configuration, is needed. A possible tilt rotor configuration is depicted in figure AM–18.

LUH. A Light Utility Helicopter with performance and physical characteristics compatible with the ASH is needed to assume many of the mission associated with aviation support as well as mobility and combat service support. A description of the LUH is provided in table AM–J.

MMAS. Improving the individual mobility of the infantry soldier has long been an Army objective. Because of high life cycle costs, high levels of maintenance and required support, and the degree of operator training required, this objective has not been attainable for the individual soldier.

An R&D study was conducted to evaluate individual lift vehicles and associated problems. The configurations assessed were:

- Helicopter
- Jet Belt (Williams)
- Ducted Bypass Engine (Garrett)
- Tandem Shrouded Fans
- Winged Side-By-Side Shrouded Fans

The system description of a Mini-Manned Aircraft System is shown in table AM–Y. A possible helicopter configuration including aircraft characteristics and associated weights is shown in figure AM–19, a ducted fan version is shown in figure AM–20, and a fan-in-wing version is shown in figure AM–21.

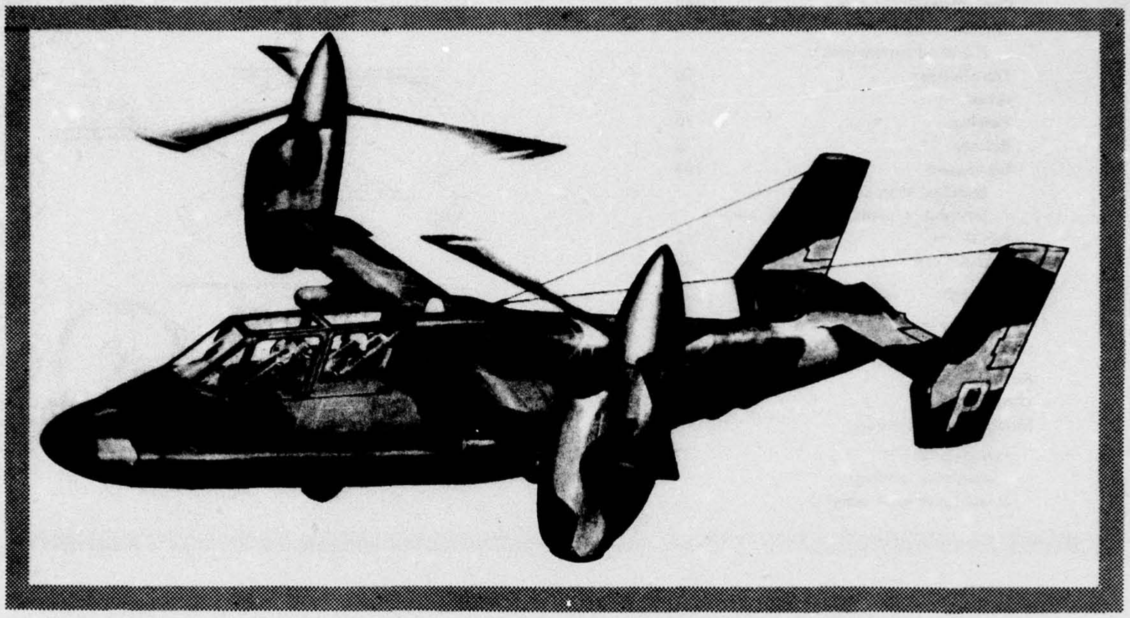


Figure AM–18. Tilt rotor version of an aviation support role aircraft.

TABLE AM–Y
MINI-MANNED AIRCRAFT SYSTEM DESCRIPTION

MISSION	• Extend intelligence-gathering capability of the ground commander. • Deployment of small man-portable defense weapon systems.	
KEY PERFORMANCE FACTOR	• NOE maneuverability. • Unique survivability capabilities.	• Low cost. • Easy to operate.
PERFORMANCE CHARACTERISTICS	• Hover 4000 ft, 95°F, OGE • 40-60 knot airspeed. • 1/2-hour endurance. • Operation in adverse weather conditions.	• 30 mile range. • 300 lb payload.
PHYSICAL CHARACTERISTICS	• Highly survivable. • Minimum maintenance.	• 3-5 hr solo training. • 40-60 hr flight training.
SYSTEM APPLICATION	• Provide mobility to the individual soldier.	

CHARACTERISTICS	
Weights (lb.)	
Crew (2-man)	400
Engine – Piston	310
(15 lb oil system incl.)	
Transmission	68
Rotor	50
Fuselage	70
Battery	25
Equipment	150
(Landing gear, controls, *furnishings, communications, etc.)*	
Tail Rotor	12
Fuel & Tank	68
Gross weight	1180
Horsepower (hp)	159
Fuel (gal.)	9.7
Rotor radius (ft.)	6.85
Chord (ft.)	.805
Maneuver factor – g	1.5 min
Tip weights (lb.)	27
(Emergency landing)	
(Included in gross weight)	

CONFIGURATION

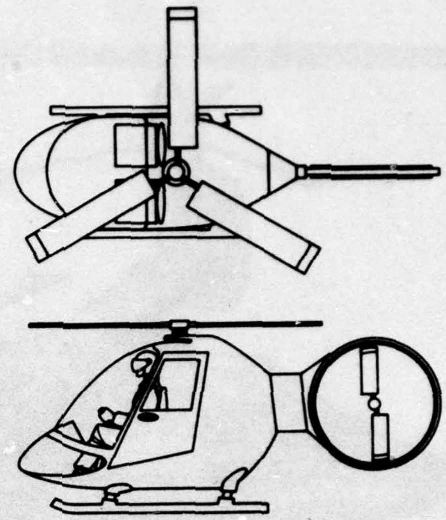


Figure AM–19. Helicopter version of MMAS.

CHARACTERISTICS	
Weights (lb.)	
Crew (2-man)	400
Engine – Turbo – Shaft	247
(15 lb. oil sys. incl.)	
Fuselage	103
Fuel & Tank	152
Fan	188
Ducts	83
Battery	25
Landing Gear	58
Equip. & Furnishings	80
Controls	24
Escape Equipment	100
Gross weight	1460
Horsepower (hp)	558
Fuel (gal.)	21.7
Air Flow (lb/sec)	182
Fan diameter (ft)	3.6
Exhaust velocity (FPS)	258
Maneu. Accel. – g	1.25

CONFIGURATION

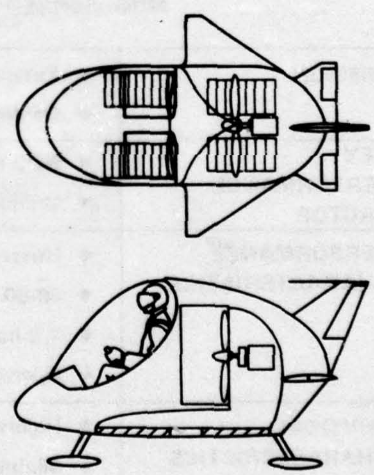


Figure AM–20. Ducted fan version of MMAS.

CHARACTERISTICS	
Weights (lb.)	
Crew (2-man)	400
Engine – Turbine	234
Cascade	116
Fan	58
Fuselage	182
Escape Equip.	100
Miscel. Equip.	160
Fuel & Tank	136
Battery	25
Transmission	33
Gross weight	1444
Horsepower (hp)	528
Fuel (gal.)	19.7
Disc loading (lb/ft^2)	25

CONFIGURATION

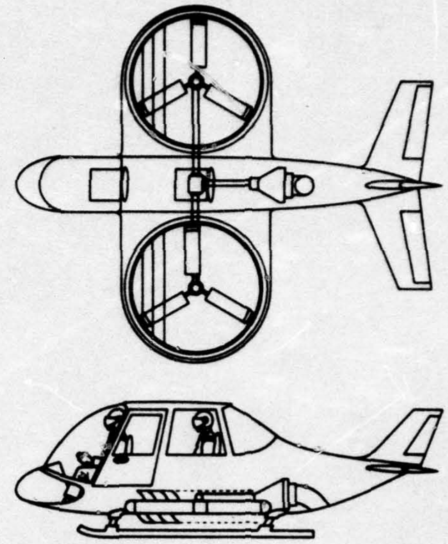


Figure AM–21. Fan-in-wing version of MMAS.

INTRODUCTION

ANALYSIS OF AIRCRAFT CONCEPTS

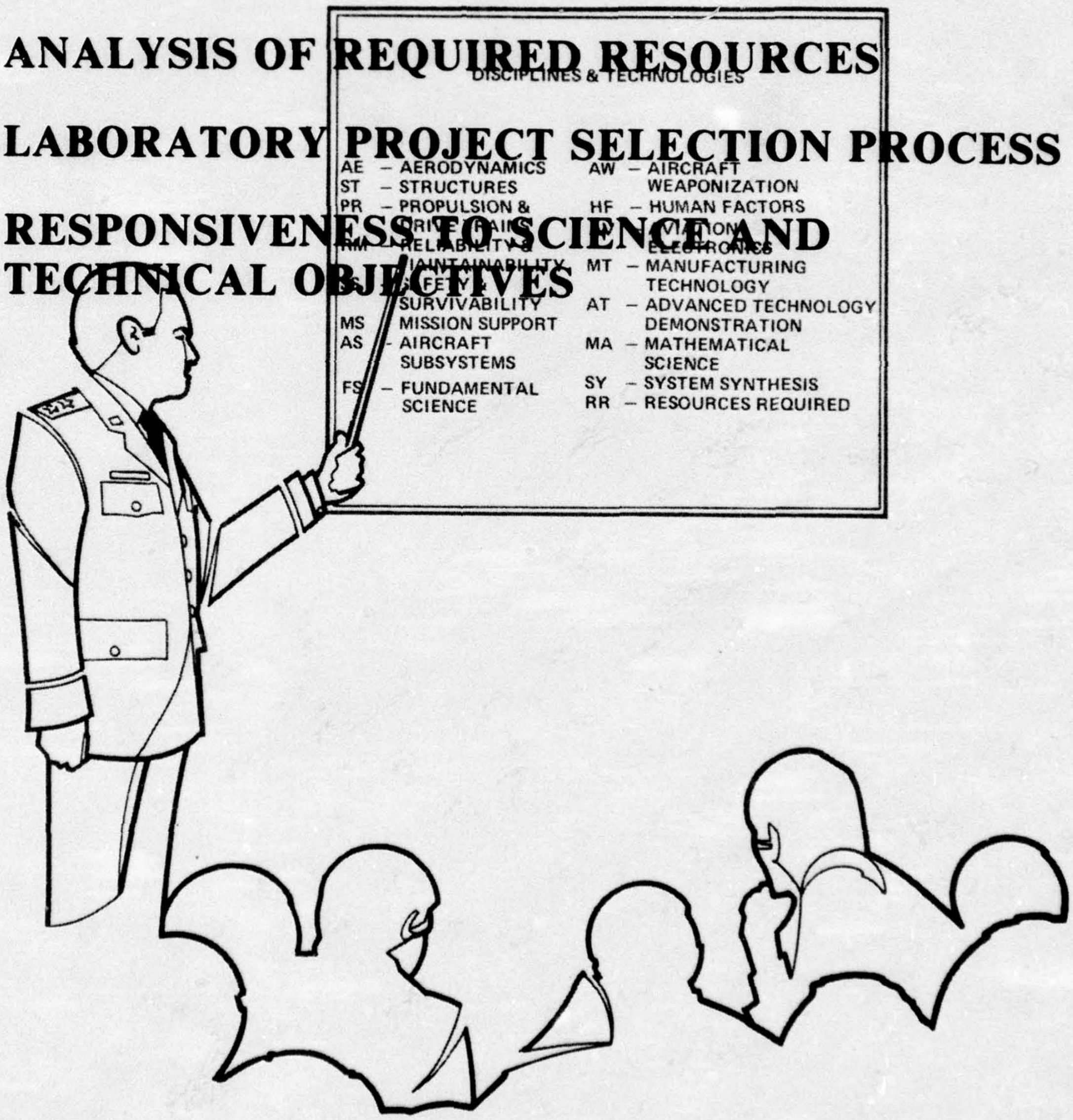
TECHNOLOGICAL REQUIREMENTS

ANALYSIS OF R&D TASKS

ANALYSIS OF REQUIRED RESOURCES

LABORATORY PROJECT SELECTION PROCESS

RESPONSIVENESS TO SCIENCE AND TECHNICAL OBJECTIVES



INTRODUCTION

The Airmobile Systems section of the Army aviation RDT&E Plan defines specific performance requirements for many of the near-term projected aircraft systems. For systems projected further into the future, more general performance requirements are described. In either case, it is possible to identify the most promising aircraft concepts to best satisfy these requirements and the research efforts needed to develop the technology base to support these concepts. In some instances, a specific airmobile system description includes technological deficiencies (voids) that must be resolved by research to permit the development of a viable system. This "demand pull" effort is discussed in the General Introduction section of the Plan.

Agility, endurance, payload, maneuvering precision, survivability, reliability, and efficiency are some of the important mission requirements that determine the ways that V/STOL technology can meet the airmobile needs of the Army. With few exceptions, projected mission requirements and proposed airmobile systems for the next two decades call for hovering capability, or at least the ability to take off and land vertically in support of forward-base operations. A variety of airplane, rotorcraft, and compound configurations conceptually have the potential to meet this requirement, but the rotary-wing configuration is presently the most attractive from an aerodynamic standpoint because of its hovering efficiency, its relatively mild downwash and noise characteristics, and its ability to autorotate. These are important factors affecting performance, detectability, and survivability.

PARAMETERS OF AIRCRAFT CONCEPTS

Chart TI–I shows a morphology of possible VTOL concepts, all but one of which have been studied seriously. However, the Army's requirements for hover efficiency and ability to live with the troops limits consideration for most of the systems to rotary-wing concepts because, as is indicated in figure TI–1, the hover efficiency is reduced and the downwash velocity increased with increasing disc loading. Although the helicopter appears to be the main contender, there are tradeoffs to be addressed because cruise performance improves with increasing disc loading.

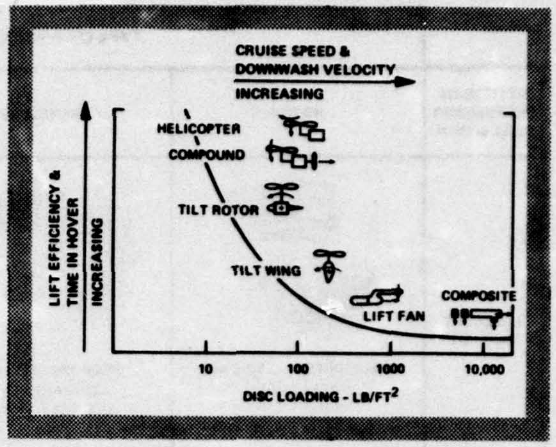
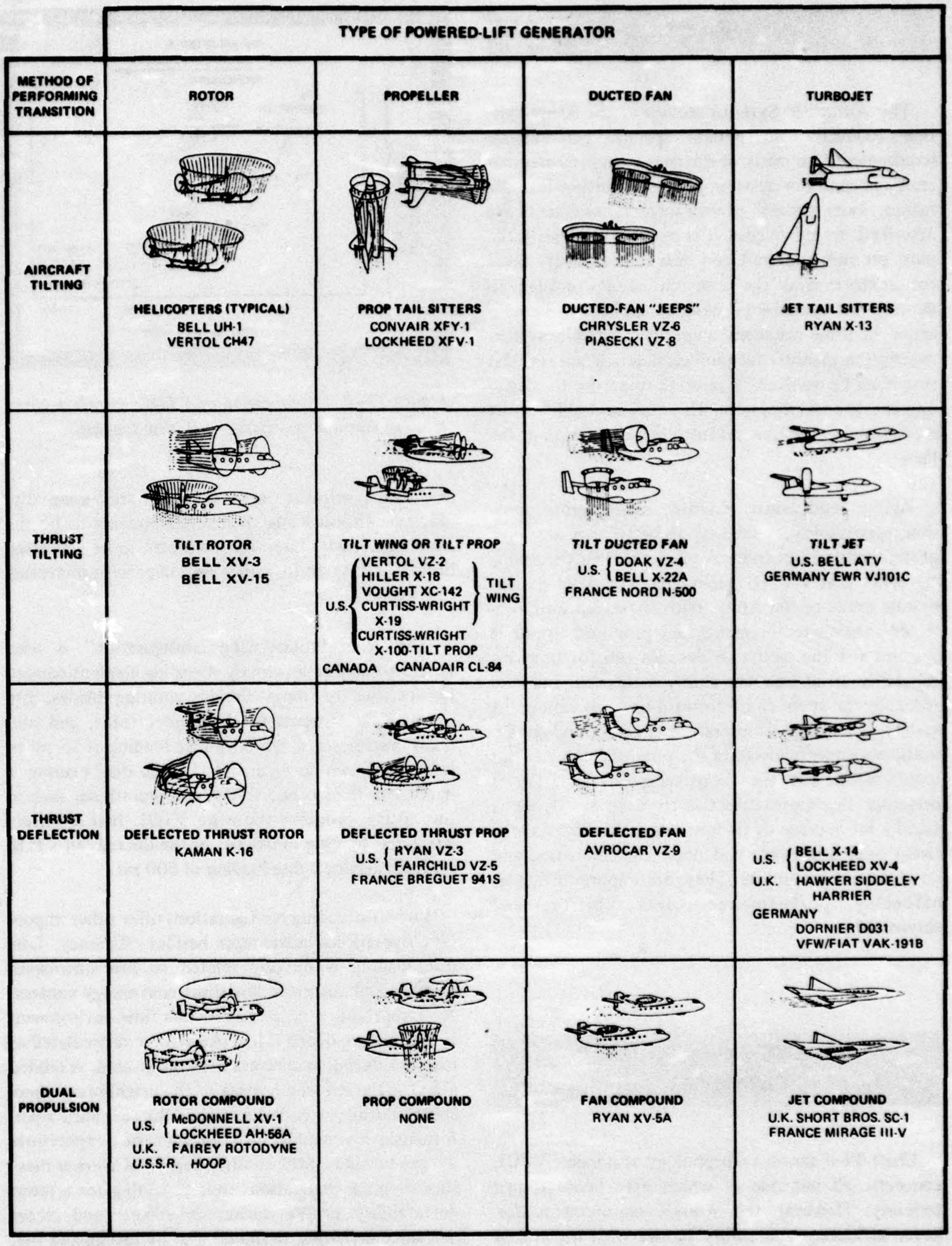


Figure TI–1. – Generation of VTOL aircraft performance characteristics with disc loading.

The term "rotary-wing configuration" is used herein to denote a primary thrusting element consisting of two or more slender rotating blades, for example, a conventional helicopter rotor, and normally having a low effective disc loading of 15 psf or less. As shown in figure TI–1, this disc loading is much less than other VTOL configurations, such as the tilting propeller-and-wing VTOL that typically has a disc loading of 50 psf, or the ducted fan VTOL typically having a disc loading of 500 psf.

Low-disc loading configurations offer other important operational advantages besides efficiency. Low disc loading is directly related to low downwash velocity and therefore low slipstream energy content. An important consequence of this flow environment is that surface debris is less likely to be recirculated or ingested during maneuvers near the ground. A related effect is the reduced heating of the neighboring atmosphere during extended hovering, thus avoiding a performance loss caused by high ambient temperatures on gas turbines. Still another benefit is a lower measure of noise generation, thus providing for a lower detectability profile during surveillance and reconnaissance activities. It should also be recognized that decreased downwash and noise are both of immeasurable importance where ground personnel operations are involved.



METHOD OF PERFORMING TRANSITION	TYPE OF POWERED-LIFT GENERATOR: ROTOR	PROPELLER	DUCTED FAN	TURBOJET
AIRCRAFT TILTING	HELICOPTERS (TYPICAL) BELL UH-1 VERTOL CH47	PROP TAIL SITTERS CONVAIR XFY-1 LOCKHEED XFV-1	DUCTED-FAN "JEEPS" CHRYSLER VZ-6 PIASECKI VZ-8	JET TAIL SITTERS RYAN X-13
THRUST TILTING	TILT ROTOR BELL XV-3 BELL XV-15	TILT WING OR TILT PROP U.S. { VERTOL VZ-2, HILLER X-18, VOUGHT XC-142, CURTISS-WRIGHT X-19 } TILT WING; CURTISS-WRIGHT X-100-TILT PROP CANADA CANADAIR CL-84	TILT DUCTED FAN U.S. { DOAK VZ-4, BELL X-22A FRANCE NORD N-500	TILT JET U.S. BELL ATV GERMANY EWR VJ101C
THRUST DEFLECTION	DEFLECTED THRUST ROTOR KAMAN K-16	DEFLECTED THRUST PROP U.S. { RYAN VZ-3, FAIRCHILD VZ-5 FRANCE BREGUET 941S	DEFLECTED FAN AVROCAR VZ-9	U.S. { BELL X-14, LOCKHEED XV-4 U.K. HAWKER SIDDELEY HARRIER GERMANY DORNIER D031, VFW/FIAT VAK-191B
DUAL PROPULSION	ROTOR COMPOUND U.S. { McDONNELL XV-1, LOCKHEED AH-56A U.K. FAIREY ROTODYNE U.S.S.R. HOOP	PROP COMPOUND NONE	FAN COMPOUND RYAN XV-5A	JET COMPOUND U.K. SHORT BROS. SC-1 FRANCE MIRAGE III-V

Chart TI–I. VTOL Configuration

The user's concern, when faced with evaluating alternative aircraft, is how effectively each will perform the missions he requires. How this is accomplished through design detail is of little concern to him; however, it is important for the potential rotary-wing VTOL customer to know what influence particular mission requirements will have on the attainable mission effectiveness. Hover duration, for example, is one requirement that must be weighed against cruise performance (figure TI–2). Other requirements include built-in facilities and fixed useful load (which reduce disposable load), altitude and temperature requirements (which decrease gross weight and increase empty-to-gross weight ratio), size (which has square-cubed law implications), and airframe configuration (crane, internal cargo, etc.).

Performance requirements result from the specific mission. The ability to perform the mission is determined by basic system efficiencies, configuration design variables, weight allowance for special equipment and facilities, range, endurance, hover time, derating for altitude and temperature, and other such factors. Configuration design variables, such as disc loading, rotor solidity, rotor tip speed, and compounding, are manipulated by the designer to optimize the design. Basic system efficiencies such as rotor figure of merit, airframe drag, cruise lift/propulsion efficiency, engine specific fuel consumption, and empty-to-design gross weight ratio are functions of the state-of-the-art. The relative impact of typical variance in mission requirements and system efficiencies on the sea level, standard-day capability of a rotary-wing vehicle is shown in figure TI–3.

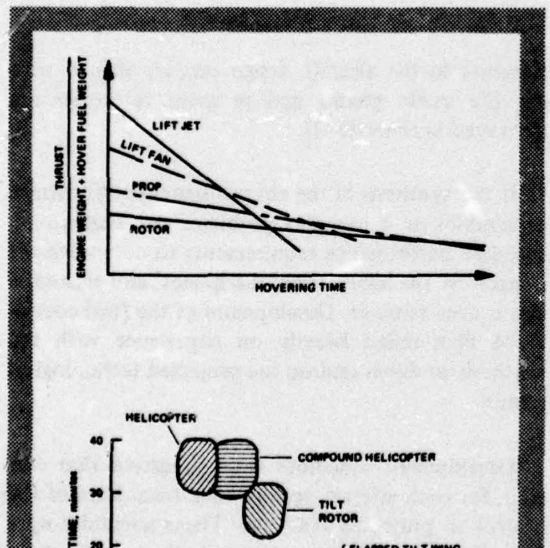


Figure TI–2.– Hovering and cruise performance.

For this Plan, all possible aircraft concepts, including VTOL, V/STOL, and STOL, were considered. Those adjudged most probable to meet projected performance requirements for each requirement are shown in figure TI–4. Projected IOC dates for each aircraft system as determined from available documentation and constrained by political and fiscal limitations were established (see System Introduction Section for listing of established or anticipated IOC dates of listed systems – classified version of the Plan). Since long-term projections are less certain in detail and more basic in technological research implications, more options are retained, whereas, for a near-term system, only a single system concept remains feasible.

TECHNOLOGICAL REQUIREMENTS

The missions, concepts, and assigned IOC dates represent the current projection of the Army's aviation needs that have been analyzed to identify technology gaps. Following estimation of the performance requirements and operational needs, it was then possible to predict the technological developments that must be pursued in support of the specific systems and concepts that were identified. The mechanism for identifying, justifying, and establishing research projects and tasks to provide development data for integration into the system design of future aircraft is the continual conduct of conceptual and design studies of the options for the various mission requirements. Required advances in the disciplines and supporting technologies are identified by such studies. (The studies also form the basis of a development plan.) However, the chief characteristics of air vehicle technology are its interdisciplinary nature and very broad spectrum. It is important to recognize the interfaces of the many components, equipments, disciplines, and sciences that make up the totality of the airmobile systems design problem. The many faceted interrelationships of the essential

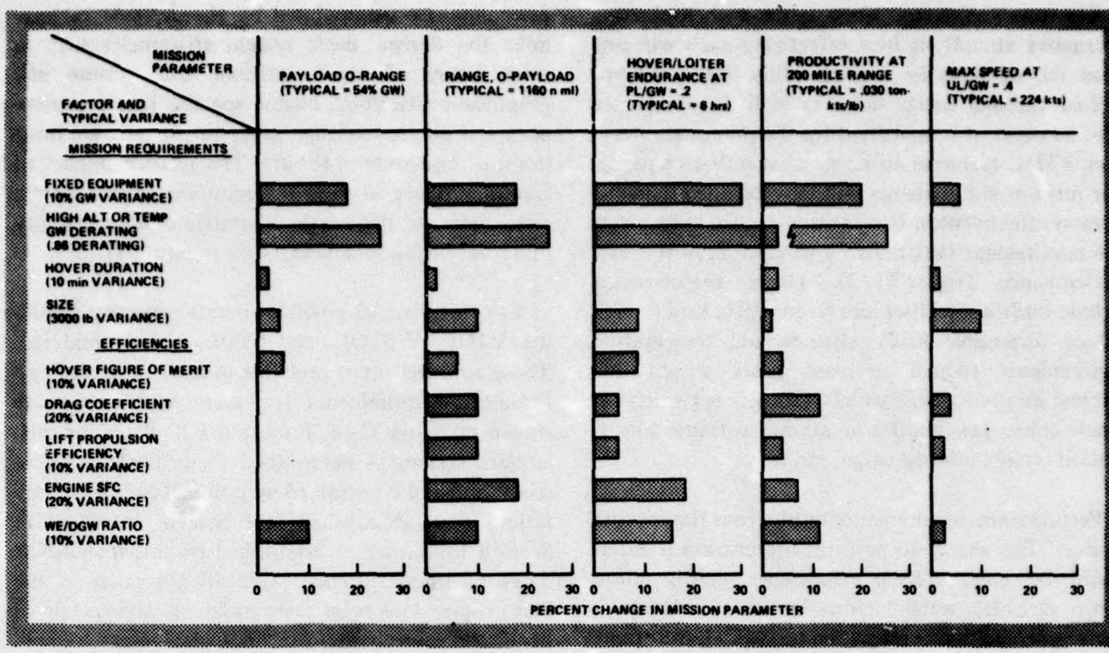


Figure TI–3.– Relative impact of typical variance in mission requirements and system deficiencies on sea level standard capability.

CANDIDATE CONCEPTS	AAH	UTTAS	ASH	RPV	CH-47D	HLH	OV-X	SUR/VTOL	AAWS	LAH	LUH	MMAS
VTOL												
AUTOGYRO				X								
HELICOPTER	X	X	X	X	X	X				X	X	X
TILT ROTOR								X	X			
ROTOR COMPOUND				X					X			X
TILT WING								X	X			
TILT DUCTED FAN									X			X
DEFLECTED FAN									X			X
FAN COMPOUND									X			X
DEFLECTED JET									X			X
STOL												
HIGH-LIFT DEVICES				X				X				
POWER AUGMENTED LIFT				X								
CTOL												
CONVENTIONAL				X			X					
OTHER												
LIGHTER THAN AIR						X						

Figure TI–4.– Concepts for Army air mobility missions.

elements in the aircraft design process aligned with the life cycle phases and program categories are portrayed in chart TI–II.

If the synthesis of the aircraft system performance capabilities is a complex problem, the analysis of specified performance requirements to determine the impact on the subsystems, disciplines, and technologies is even more so. Development of the final coordinated Plan relied heavily on experience with the synthesis problem and on the projected technological trends.

Development schedules were predicted that covered, for each aircraft option, time from start of the project to projected IOC date. These schedules were used to estimate development lead time required, thus establishing the time required for technological objectives to be achieved to meet the IOC date. The life cycle of a new aircraft system and the time and method by which technological advancements are incorporated into it vary greatly, depending upon the complexity of the system, availability of new advancements and their cost effectiveness. In general, a new aircraft experiences a life cycle that includes

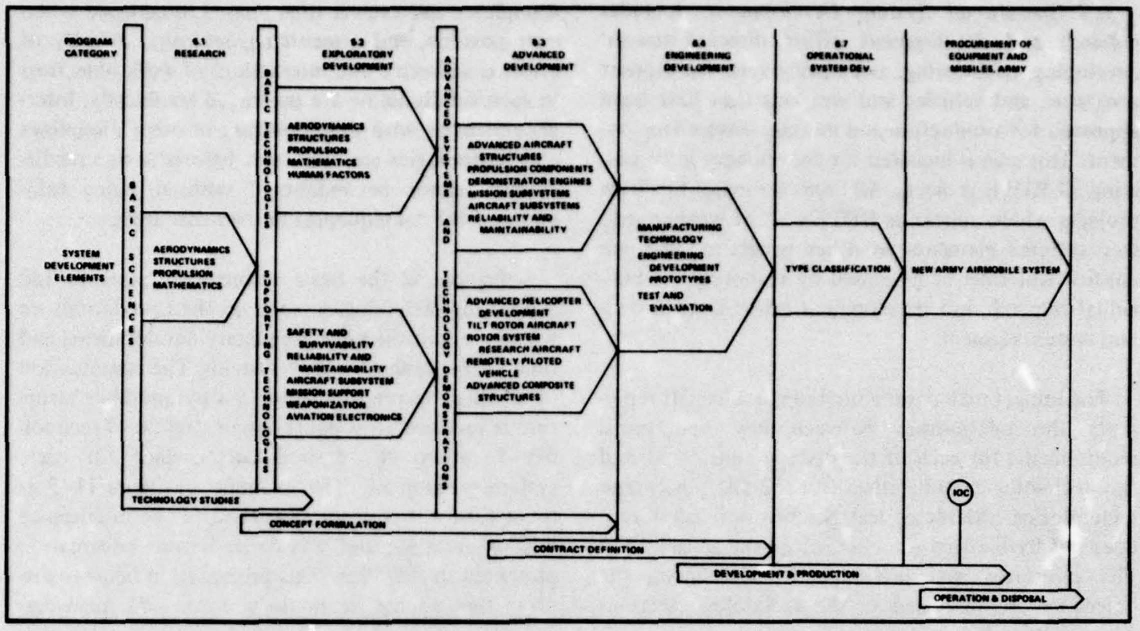


Chart TI–II. Relationships of Technologies for New Airmobile Systems

most of the elements shown in chart TI–II. It was assumed that contract definition (beginning engineering development) occurred, on the average, about 8 years prior to IOC and initiation of exploratory development was required about 7 years prior to contract definition. The objective in all cases was to have completely developed and demonstrated technology on the shelf, ready for engineering design of the system, in a timely manner prior to engineering development.

The RDT&E program structure was organized based on the categories as shown in chart TI–II with category definition as presented below:

6.1 Research. Includes all effort directed toward increased knowledge of natural phenomena and environment. The primary aim is to gain fuller knowledge and/or understanding of the hard sciences, e.g., physics, chemistry, biomedical, engineering, mathematics. It does not include the solving of behavioral and social science problems that have a clear direct military application, nor does it include the solving of human relations and factors which occur in conjunction with human use and acceptance in a man/group application to equipment, materiel, and/or systems. Research efforts result in an increased knowledge of natural phenomena and/or improved technology.

6.2 Exploratory Development. Includes all effort directed toward solving specific military problems short of major developments projects. It may vary from fairly fundamental applied research to quite sophisticated prototype hardware, study, programming, and planning efforts. It would thus include studies and minor development efforts. The dominant characteristic is that the effort is pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters.

6.3 Advanced Development. Includes all projects which have moved into developing hardware for experimental or operational test. It is characterized by line item projects, and program control is exercised on a project basis. Another descriptive characteristic is the design of the items being directed toward hardware for test or experimentation as opposed to items designed and engineered for eventual military service use.

6.4 Engineering Development. Includes those development projects being engineered for military service use but which have not yet been approved for procurement or operation. It is characterized by major line item projects, and program control is exercised by reviewing individual projects.

6.7 Operational System Development. Includes research and development effort directed toward developing, engineering, and testing systems; support programs; and vehicles and weapons that have been approved for production and military service employment. This area is included for convenience in considering all RDTE projects. All items are major line item projects which appear as RDTE cost of weapon project systems elements in other programs. Program control will thus be exercised by reviewing the individual research and development effort in each weapon system element.

The impact matrix presented in chart TI–III represents the relationship between key operational requirements for each of the systems considered, and the technological objectives for 12 disciplines and technologies. (Mathematical Science not listed as it does not have a first-order effect on the areas listed.) The interfaces and interdependencies among the objectives are discussed in the technology sections which follow this introduction.

The objectives of the activities in each of the disciplines and technologies have been quantified, wherever possible, in accordance with the performance and timing requirements of the projected airmobile systems. In some areas, particularly the basic sciences, this has not been entirely possible because the performance requirements of a particular system cannot be related directly or quantitatively to an incremental advance in a particular discipline or because a definitive parameter has not yet been defined in that discipline and, in fact, research is directed towards the definition of such a parameter.

The major portion of the planned research effort is directed toward rotary-wing aircraft, which are expected to be the prime source of Army air power in the future. However, other subsonic aircraft, capable of vertical or short takeoff and landing, have not been precluded.

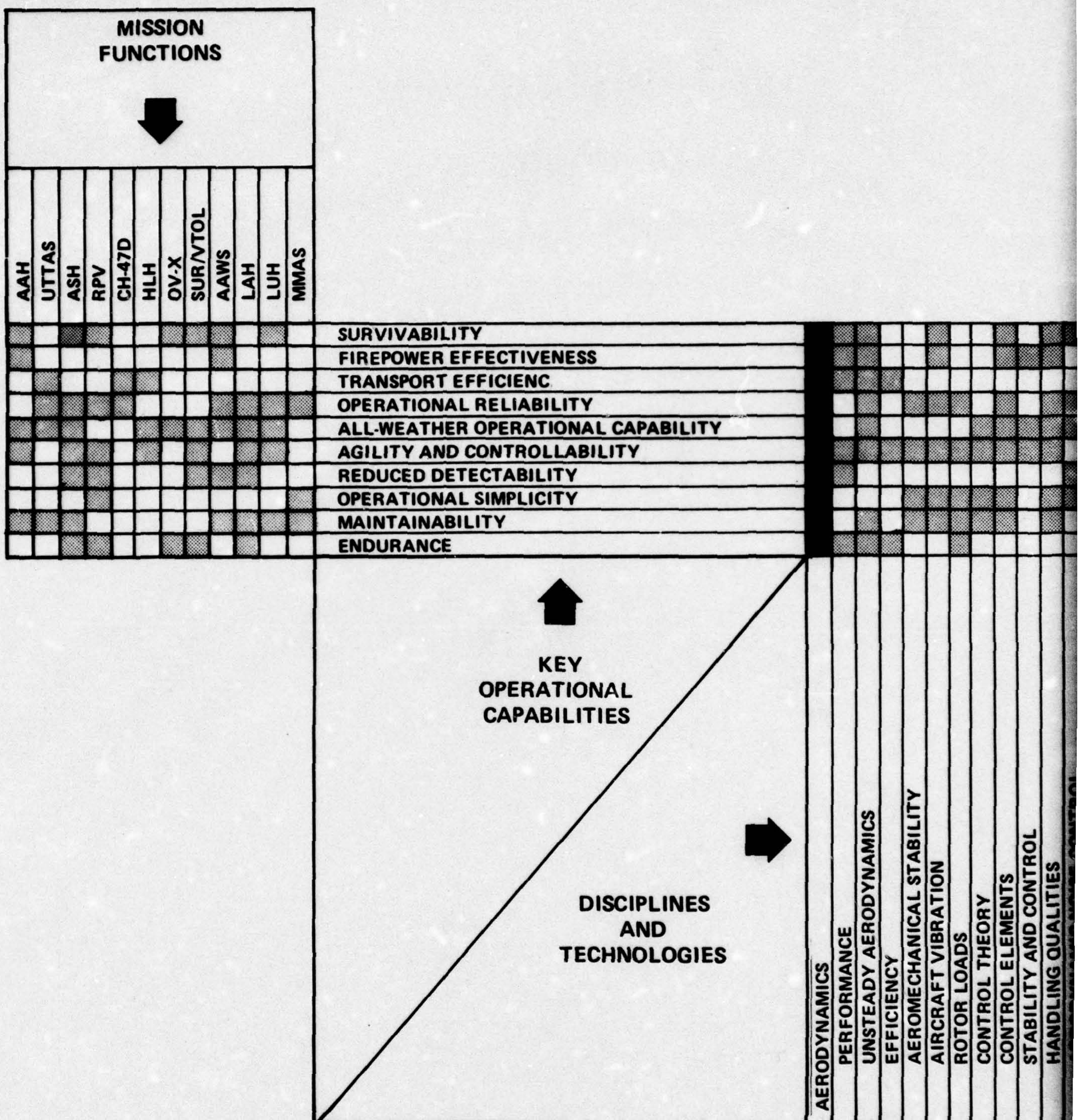
ANALYSIS OF R&D TASKS

The 13 disciplines categorized as airmobile technology with supporting disciplines of Advanced Technology Demonstration, Aircraft System Synthesis, Fundamental Science, and Resources Required are presented in the following subsections of the Plan. All work objectives are categorized within the key subdisciplines and each is time phased, quantified wherever possible, and presented graphically. Priority of effort is addressed and interactions of work objectives in each subdiscipline are portrayed graphically. Interdependencies with developments in other disciplines and technologies are discussed. Efforts in one subdiscipline cannot be redirected without being fully aware of the consequences in the other areas.

Advances in the basic aeronautical sciences and supporting technologies make up the foundations on which are laid the interdisciplinary developments and finally, the design for new systems. The combination of all these accomplishments in a pyramid-like structure is required to support demonstration of technology to attain the desired performance for each system/component. The example of figure TI–5 is for a tilt-rotor concept as applied to the intelligence mission function and was derived from information presented in this Plan. This presentation helps to display the pacing technology areas and provides another aspect of the interdependencies of accomplishments in the sequential, mission-oriented sense. Similar graphical presentations can be drawn from this Plan for every system and concept projected herein and for any other to which the technology pertains.

It is apparent from an analysis of this R&D Plan that VTOL aircraft technology is expected to experience significant advances over the 20-year time frame that is addressed. Improved rotor performance reduced structural weight ratios, and reduced specific fuel consumption are certain to be realized. Solid-state, integrated microelectronic circuitry will enable the provision of onboard miniature computers and other devices that will greatly enhance navigation, control, and fire-control capabilities over current systems, making possible all-weather and night operations, even in the nap-of-the-earth. Better reliability and reduced maintenance requirements are sure to evolve, as will self-contained test capability. A dominant improvement sought is development of aircraft that can take (and avoid) punishment meted by the hostile environment typical of Army aviation.

The advances in aircraft technology can only become an integral part of the R&D cycle when the advancement has been validated by component or system demonstration in actual or simulated flight conditions. The near-term technological advances undergoing validation are discussed in considerable detail in the Plan.



MISSION FUNCTIONS
AAH
UTTAS
ASH
RPV
CH-47D
HLH
OV-X
SUR/VTOL
AAWS
LAH
LUH
MMAS
SURVIVABILITY
FIREPOWER EFFECTIVENESS
TRANSPORT EFFICIENC
OPERATIONAL RELIABILITY
ALL-WEATHER OPERATIONAL CAPABILITY
AGILITY AND CONTROLLABILITY
REDUCED DETECTABILITY
OPERATIONAL SIMPLICITY
MAINTAINABILITY
ENDURANCE
KEY OPERATIONAL CAPABILITIES
DISCIPLINES AND TECHNOLOGIES
AERODYNAMICS
PERFORMANCE
UNSTEADY AERODYNAMICS
EFFICIENCY
AEROMECHANICAL STABILITY
AIRCRAFT VIBRATION
ROTOR LOADS
CONTROL THEORY
CONTROL ELEMENTS
STABILITY AND CONTRIES
HANDLING QUALITIES

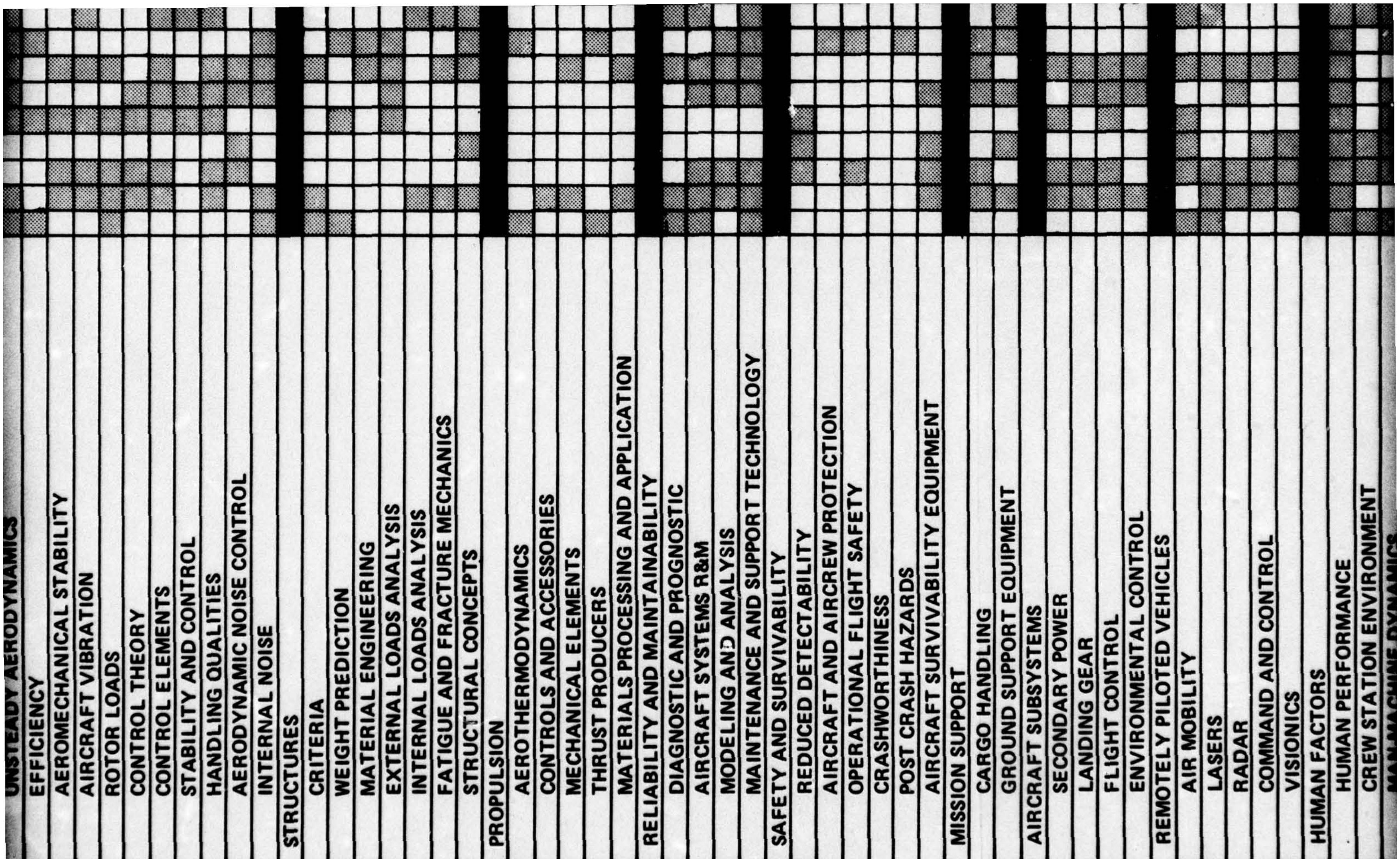
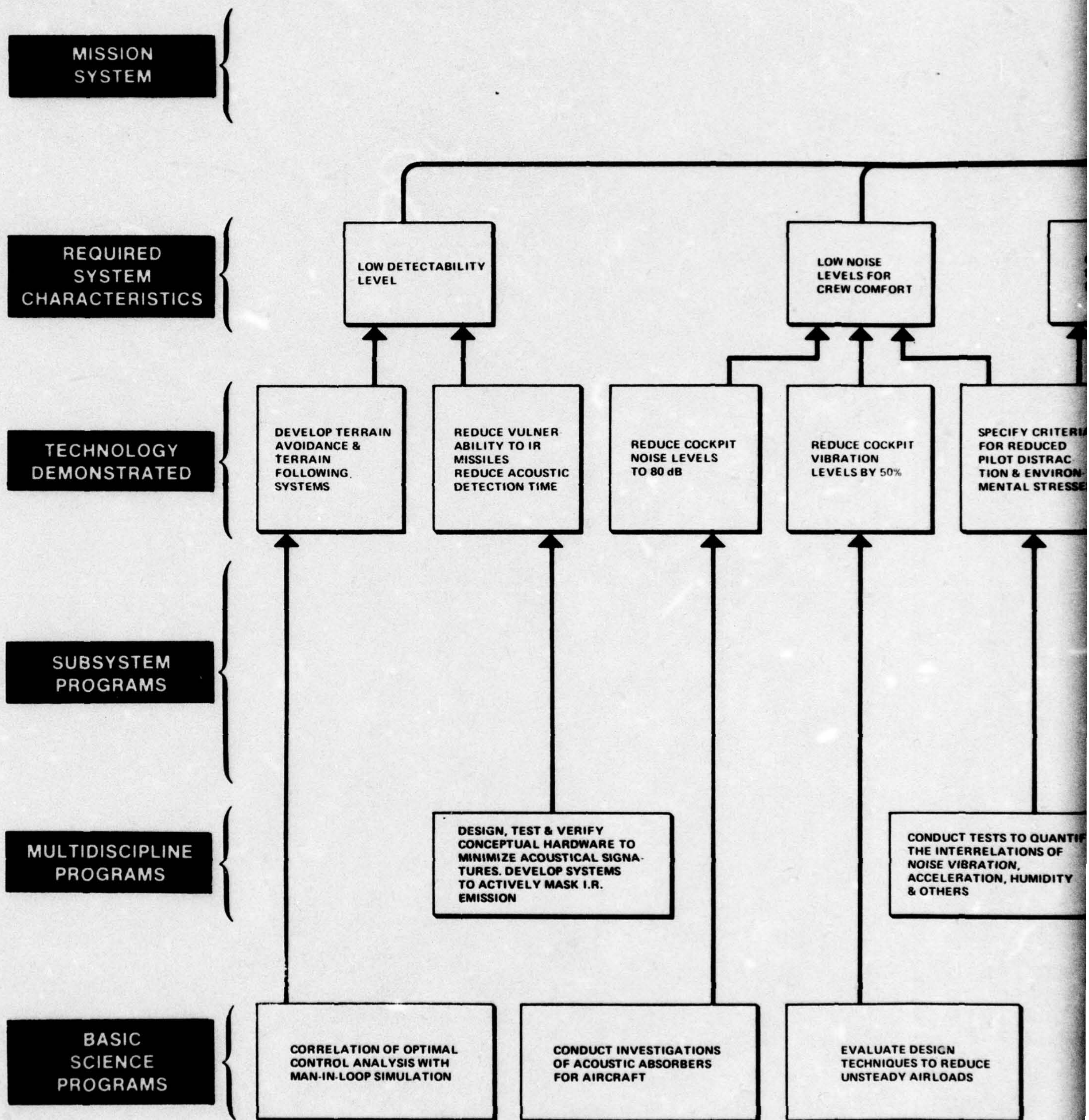


Chart TI–III. Technology Impact Matrix

FLIGHT CONTROL
ENVIRONMENTAL CONTROL
REMOTELY PILOTED VEHICLES
AIR MOBILITY
LASERS
RADAR
COMMAND AND CONTROL
VISIONICS
HUMAN FACTORS
HUMAN PERFORMANCE
CREW STATION ENVIRONMENT
MAN-MACHINE DYNAMICS
TRAINING AND MAINTENANCE
AVIATION ELECTRONICS
AVIONICS SYSTEMS
COMMUNICATIONS
NAVIGATION
TACTICAL LANDING
AIR TRAFFIC MANAGEMENT
ENVIRONMENTAL SENSING
INSTRUMENTATION
SURVEILLANCE AND TARGET ACQUISITION
NIGHT VISION SYSTEMS
OTHER
MANUFACTURING TECHNOLOGY
AIRCRAFT WEAPONIZATION

PRECEDING PAGE BLANK NOT FILMED



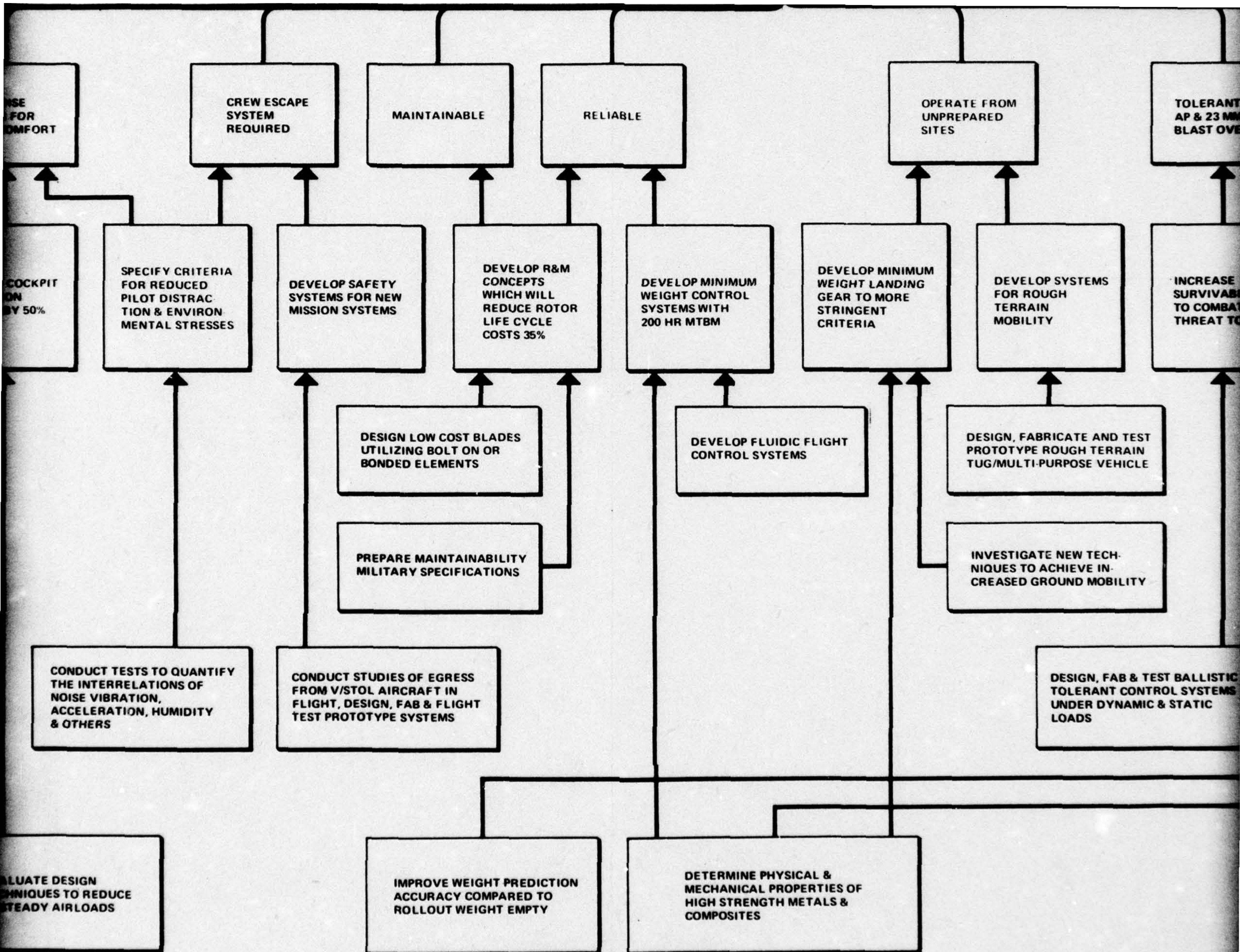
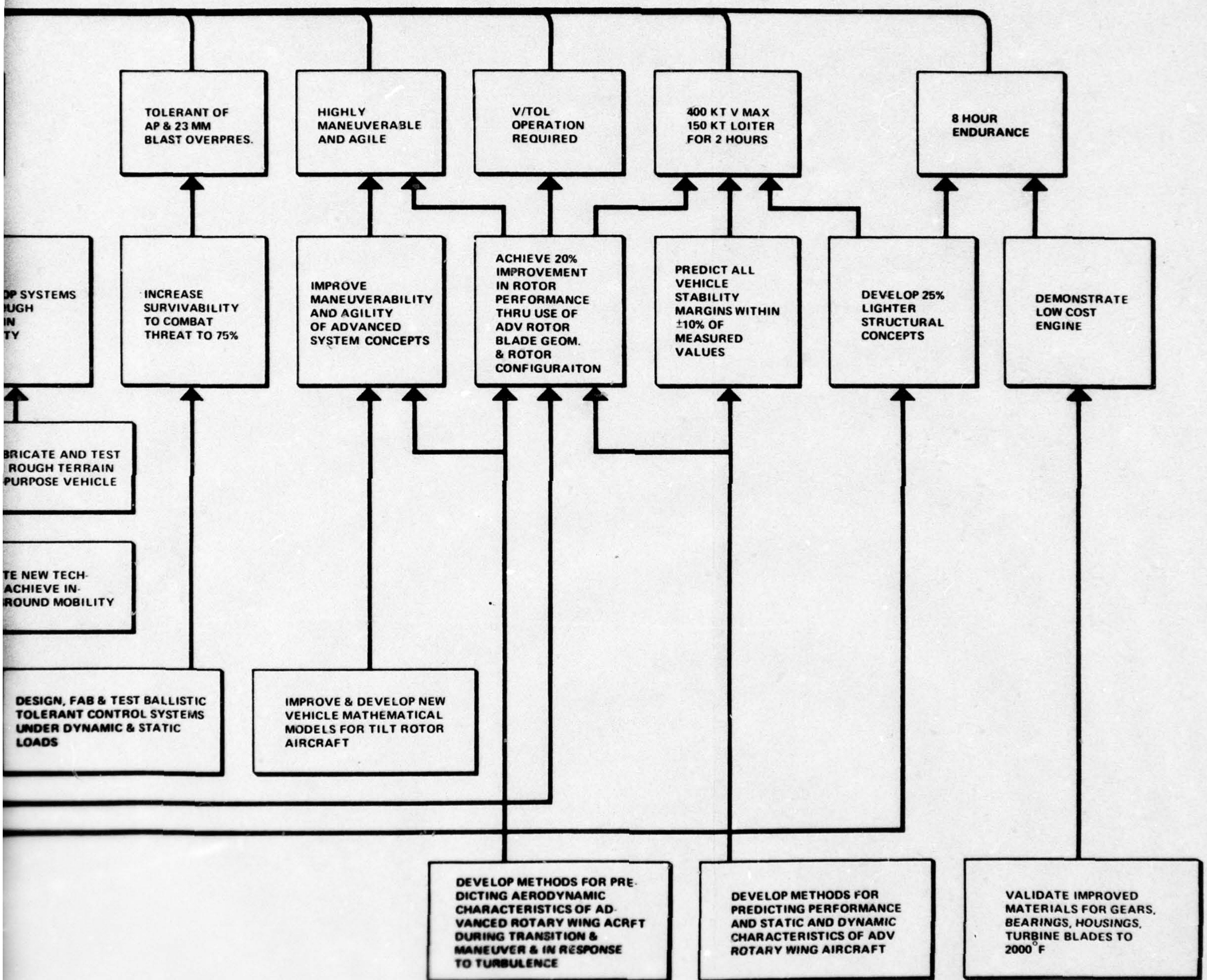


Figure TI–5. Pyramidal structure of accomplishments for SUR/VTOL and tilt rotor.

3


TOLERANT OF AP & 23 MM BLAST OVERPRES.
HIGHLY MANEUVERABLE AND AGILE
V/TOL OPERATION REQUIRED
400 KT V MAX 150 KT LOITER FOR 2 HOURS
8 HOUR ENDURANCE
OP SYSTEMS UGH IN TY
INCREASE SURVIVABILITY TO COMBAT THREAT TO 75%
IMPROVE MANEUVERABILITY AND AGILITY OF ADVANCED SYSTEM CONCEPTS
ACHIEVE 20% IMPROVEMENT IN ROTOR PERFORMANCE THRU USE OF ADV ROTOR BLADE GEOM. & ROTOR CONFIGURAITON
PREDICT ALL VEHICLE STABILITY MARGINS WITHIN ±10% OF MEASURED VALUES
DEVELOP 25% LIGHTER STRUCTURAL CONCEPTS
DEMONSTRATE LOW COST ENGINE
BRICATE AND TEST ROUGH TERRAIN PURPOSE VEHICLE
TE NEW TECH- ACHIEVE IN- ROUND MOBILITY
DESIGN, FAB & TEST BALLISTIC TOLERANT CONTROL SYSTEMS UNDER DYNAMIC & STATIC LOADS
IMPROVE & DEVELOP NEW VEHICLE MATHEMATICAL MODELS FOR TILT ROTOR AIRCRAFT
DEVELOP METHODS FOR PRE- DICTING AERODYNAMIC CHARACTERISTICS OF AD- VANCED ROTARY WING ACRFT DURING TRANSITION & MANEUVER & IN RESPONSE TO TURBULENCE
DEVELOP METHODS FOR PREDICTING PERFORMANCE AND STATIC AND DYNAMIC CHARACTERISTICS OF ADV ROTARY WING AIRCRAFT
VALIDATE IMPROVED MATERIALS FOR GEARS, BEARINGS, HOUSINGS, TURBINE BLADES TO 2000°F

ANALYSIS OF REQUIRED RESOURCES

The precise quantitative magnitude of technological improvement that can be achieved is governed by other than purely technical considerations. Political policy is a major element but impossible to predict and has been ignored. Of major importance are budgetary and schedule constraints that limit the amount of design optimization and technological advance. Under conditions of limited resources, imposed economics, and prescribed goals, a logical resource allocation methodology is the key to orderly progress.

The issue of resource requirements is discussed in section RR – Resources Required. However, it is reiterated that this document presents the Plan for research and development in Army aviation and is not a program. The Plan becomes the program when the required resources in terms of funds, facilities, and personnel are provided to enable its implementation.

It is not likely that all the efforts described in this plan would be pursued or all the goals achieved. Furthermore, the available options and alternatives to perform the given task diminish with time and, consequently, estimates of resource requirements are valid only on a relatively short-term basis.

LABORATORY PROJECT SELECTION PROCESS

INTRODUCTION

As stated previously, the superiority of future Army airmobile systems depends on the availability and exploration of new scientific knowledge and the development of a firm technology base to meet projected requirements. Unfortunately, there are never enough resources to undertake all of the research projects that optimum planning would indicate necessary for the development of that technology base. In many cases there are more feasible technical alternatives available to solve a particular problem than can be economically supported. The problem that faces the R&D manager is to decide which efforts are to be supported and which goals can be achieved under the conditions of limited resources. The procedure described herein and implemented in most of the following technology sections (see Technological Program Direction subsection) is the AMRDL method for solving the project selection problem.

To fully understand and appreciate AMRDL's Project Selection Process it is first necessary to establish and define the Aircraft Systems Synthesis concept. To define Aircraft Systems Synthesis, it is necessary to use the classical definitions of *analysis* and *synthesis*. Consider a process, or system, or plant with inputs and outputs. If the process and inputs are well defined, then *analysis* means that behavior of the process is analyzed in terms of outputs. On the other hand, if inputs are given and desired outputs are also specified, then the construction of the system or the process which would yield the desired outputs in view of the given inputs constitutes the *synthesis* process. Aircraft Systems Synthesis, then, means the construction of the Army Aviation R&D Program (process), given the AVSCOM mission and resources (inputs) to yield future airmobile systems and technologies (outputs). The following diagram, figure TI–6, portrays this Aircraft Systems Synthesis concept.

Project selection is that portion of the Aircraft Systems Synthesis concept which is directed to effect

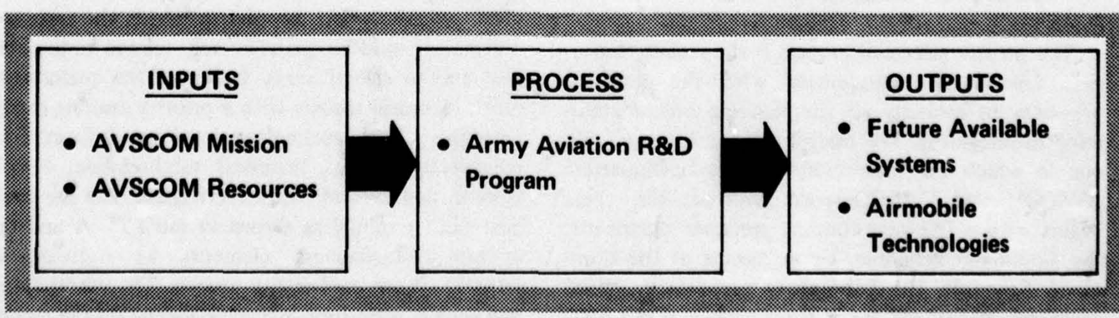


Figure TI–6. Aircraft systems synthesis concept.

a balanced R&D program. Other activities of the Aircraft Systems Synthesis are found in the Aircraft Systems Synthesis Section (SY) of the Plan.

Development of the project selection process requires some type of rational, systematic procedure containing the major elements of airmobile R&D objectives, priorities, and rational (OPR), and resulting in the form of major Laboratory thrusts (see individual technology sections for OPR major thrusts pertaining to that technology).

APPROACH

The following objectives are desirable attributes in the design of a methodology for the project selection process:

- The system must be amenable to the incorporation of both quantitative and qualitative variables.
- Input requirements should rely primarily on data durrently available or required for other management activities. Time requirements to provide additional data should be low.
- The methodology should be capable of processing nonlinear benefit/cost relationships, identifying differences of opinion, conducting sensitivity analyses on data inputs of greatest uncertainty, and permitting rapid reassessment when key parameters change.
- A mathematical model capable of handling R&D planning inputs whose mechanisms are necessarily based on subjective judgments with considerable uncertainty should be developed. The model's analytical properties should be readily understandable by management.
- The use of the methodology should promote participative management.

The project selection process is the means to provide Laboratory management with the guidance necessary to properly tie the planning and programming to budgeting. The budget process is a recurring one in which the Laboratory and its Headquarters AVSCOM and DARCOM are involved. The cycle begins with a five-year funding guidance document, the Command Schedule. Upon receipt of the Command Schedule, the Laboratory prepares proposed programs and plans for a three-year period (AMC Form 1534 – RDTE Program Data Sheet and DD Form 1634 – Research and Development Planning Summary) in response to the guidance document. These programs and plans are then submitted to DARCOM through AVSCOM for review. Guidance (AMC Form 1006 – Program Directive/Program Change Request) from DARCOM is issued which constitutes expected funding for the next fiscal year. Proposed programs (AMC Form 1006A – Program Directive/Program Change Request) are then prepared by the Laboratory detailing specific efforts to be undertaken in view of this guidance. The cycle repeats each fiscal year with the issuance of a new Command Schedule.

APPLICATION

The development of the Laboratory Project Selection Process requires:

- Clear definition of fundamental laboratory technical objectives,
- Priority of these objectives,
- Rationale supporting the technical thrust (effort).

For each of AMRDL's airmobile technology disciplines, a set of objectives, priorities and rationale (OPR) have been developed and are presented in the program section for each of the technology disciplines (Aviation electronics and manufacturing technology are excluded since AMRDL is not the lead organization for these efforts).

Each technology is subdivided into a set of subdisciplines and near-term technical objectives are developed and stated. Additionally, vehicle subsystems elements pertinent to the particular technology discipline are identified. There is an interdependency between technical objectives, subdisciplines, vehicle subsystems and eventual system effectiveness. The ideal process would be one in which the technical objectives could be quantitatively related to incurred cost and to effectiveness. In lieu of the quantitative ideal, technical thrusts with a priority ranking can be developed. Each technology is reviewed from three considerations, i.e., technical subdiscipline, vehicle system, and system cost/effectiveness. The life cycle cost (LCC) model as shown in table TI–A and the system effectiveness elements as outlined in table TI–B are used in this process. The subdiscipline and vehicle subsystem elements depend on the technical discipline. The near-term technical objectives are

considered in terms of the cost/effectiveness elements, and a subjective judgment is rendered to rank the near-term objectives. The subdisciplines, vehicle subsystems and the cost/effectiveness elements are then prioritized independently. From an assessment of the priority listings and the relative ranking of the objective, the technical thrusts for a particular discipline is developed.

TABLE TI–A
LIFE CYCLE COST MODEL

Life Cycle Cost ($)	=	Development ($)
		+ Flyaway ($)
		+ Maintenance ($)
		+ POL ($)
		+ Logistical Support ($)
		+ Attrition ($)

As an example, consider the aerodynamics discipline shown in table TI–C. An assessment of that table and the near-term objectives indicates that the first priority major thrust in aerodynamics technology is consistent with the first and second objectives listed (achieve ±10% accuracy in the prediction of overall db level of aerodynamically generated noise and reduce this noise by 15% and achieve 20% improvement in predictability of stability and control characteristics) and is aimed at improving the survivability of aircraft systems to make them more effective. If an aircraft is not survivable, all other aspects of life cycle cost are relatively insignificant. In addition to surviving in a combat environment, an aircraft system must be effective, and flight controls, dynamics and performance characteristics are all tailored to produce a cost effective system. Each one of these elements is necessary to developing systems with acceptable life cycle costs, and the Laboratory thrusts are developed to provide aerodynamics technology which will result in the highest payoff in system cost in the shortest elapsed time.

TABLE TI–B
SYSTEM EFFECTIVENESS ELEMENTS

VEHICLE	MISSION
• Performance/Mission Requirements • Safety/Survivability • Raliability/Maintainability • Human Factors	• Mobility • Intelligence • Firepower • Combat Service Support • Command, Control and Communication

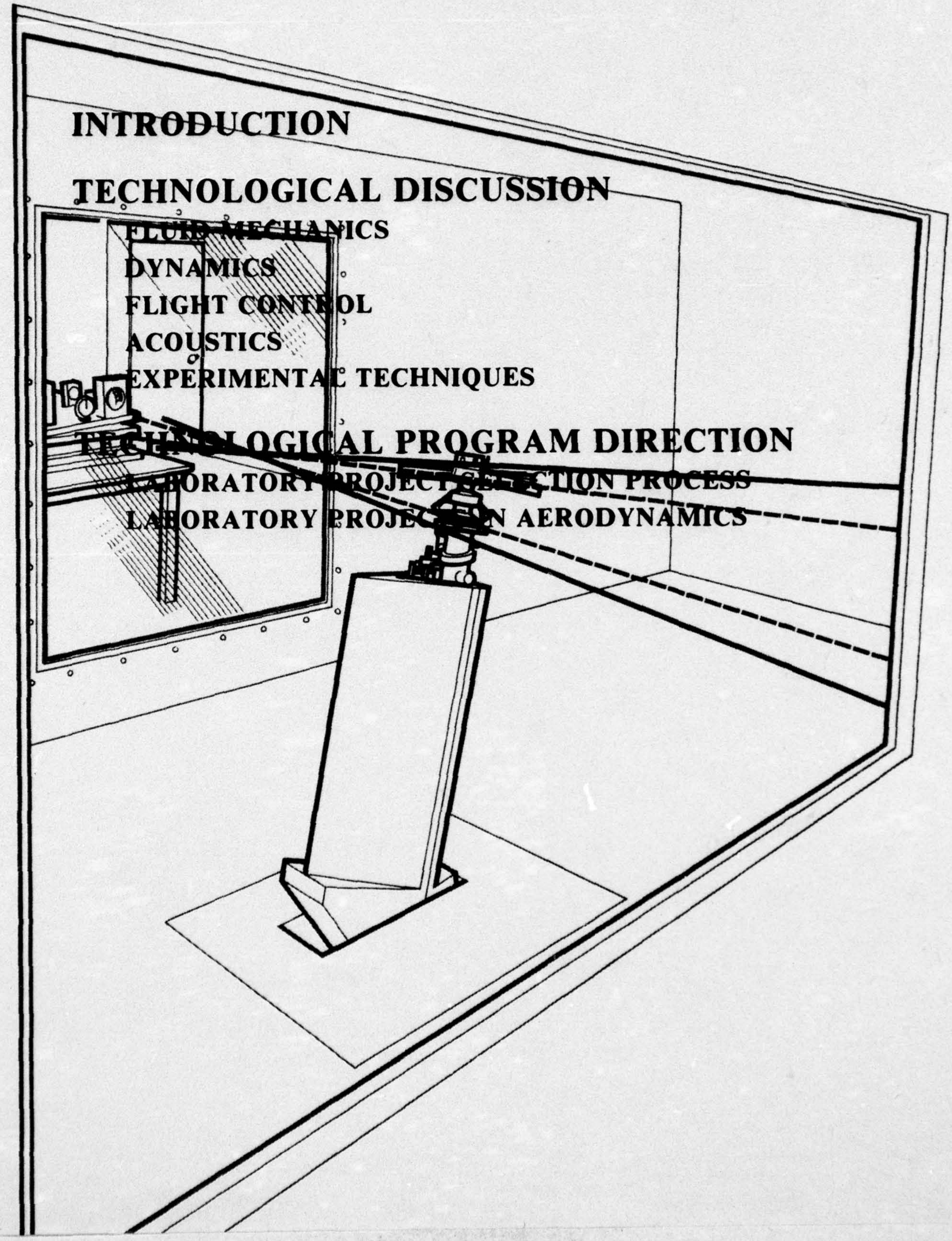
TABLE TI–C
PRIORITIZED AERODYNAMICS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Acoustics	I	• Main rotor	I	• Survivability	I
• Flight control	II	• Tail rotor	II	• R&M cost	II
• Dynamics	III	• Flight controls	III	• System cost	III
• Fluid mechanics	IV	• Fuselage	IV	• System volume	IV
				• Fuel efficiency	V

[redacted]

The key driver of the Laboratory Project Selection Process is the development of Laboratory R&D objectives from which the individual technology objectives are derived. This is a formidable task for the Laboratory management for the near-term time period let alone forecasting for a 20-year period. These objectives address the near-term and long-term R&D activities that are required for achieving the Army objectives and material needs for which AVSCOM is responsible. To the maximum extent possible the Laboratory objectives are specifically responsive to the following Army R&D guidance:

- Catalog of Approval Requirements Documents (CARDS), July 1973 (SECRET).
- DARCOM Management by Objectives (MBO) Goals.
- Science and Technology Objectives Guide, FY77 (STOG–77) (CONFIDENTIAL).



INTRODUCTION

TECHNOLOGICAL DISCUSSION

FLUID MECHANICS
DYNAMICS
FLIGHT CONTROL
ACOUSTICS
EXPERIMENTAL TECHNIQUES

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS
LABORATORY PROJECTS IN AERODYNAMICS

INTRODUCTION

The aerodynamic technology area encompasses four major subdisciplines: fluid mechanics, dynamics, flight control and acoustics. These subdisciplines are generally described as follows:

- *Fluid Mechanics.* A collection of techniques which allow for the prediction of fluid flow characteristics around bodies of various shapes. With flow patterns established, aerodynamic forces and moments acting on these bodies may be determined.
- *Dynamics.* A collection of techniques which allow for the prediction of time-dependent responses (i.e., deflection, velocity and acceleration) of rigid and elastic bodies subjected to various forms of excitation including aerodynamic forces and moments. Dynamic response predictions are used to determine system stability, vibration levels, aeroelastic divergence margins and fatigue loads.
- *Flight Control.* A collection of techniques which allow for prediction of capability for stabilizing and controlling the motion of a flight vehicle along a desired path. These techniques encompass control theory, control elements, stability and control, and handling qualities which are used to enhance task performance, extend vehicle operational capabilities, improve safety and survivability, and reduce training needs.
- *Acoustics.* A collection of techniques which allow for prediction of noise characteristics both internal and external to the vehicle producing the noise, and to determine the source of various components of the noise. With noise sources identified, reduction of vehicle noise can be systematically explored.

The ability to predict aerodynamic moments and forces accurately is fundamental to the design of cost-effective V/STOL aircraft systems, since these forces and moments permeate every facet of the design synthesis process. First, the vehicle empty weight fraction is predicted on static and fatigue loads and aeroelastic margins which are primarily due to aerodynamic phenomena. Second, fuel requirements are directly related to lift-to-drag ratio which is aerodynamic in origin. Third, installed power requirements are dictated by the combination of empty weight, fuel weight and take off lifting efficiency – all of which depend on vehicle aerodynamics. Fourth, the handling and ride qualities, (i.e., stability, control and vibration) are a direct result of aerodynamic forces and moments which must be isolated or properly controlled. And, fifth, acoustic properties are a function of aerodynamic configuration and loading which impacts external noise and detectability as well as internal noise and passenger comfort. This overall design dependence on aerodynamics technology should not be surprising, since the V/STOL aircraft operating medium is, after all, the atmosphere that surrounds the earth.

The aerodynamics portion of the Army Aviation RDT&E Plan, as well as resulting R&D programs, will, for the foreseeable future, be largely concerned with isolating and alleviating those deficiencies of rotary-wing aircraft that currently limit their operational capabilities. Over the years, rotorcraft advancements have been consistently hampered by an inadequate understanding of the highly interactive, unsteady aerodynamic environment of the rotor on a fundamental fluid mechanics level. While production demands have necessarily given rise to state-of-the-art analyses, followed by incremental semiempirical extrapolations in design, there remains a great need for detailed phenomenological investigations that further serve as guidance for the theoretician in developing more accurate analytical models.

Of the aerodynamics related phenomena that remain unmastered, the categorizations in table AE–A represent the greatest challenges to contemporary rotary-wing aerodynamics. These phenomena are discussed in the appropriate subdiscipline areas of this section and form the basis for the major aerodynamics objectives/thrusts presented later in this section.

Although emphasis has been placed on rotary-wing research, theoretical mastery of this complicated flowfield will inevitably impact the analytical treatment of all other V/STOL flow environments where compressibility, unsteadiness, three-dimensionality, wake interaction aeroelasticity, and control are important.

Regardless of the level of endeavor (i.e., basic research or applied technology), areas of investigation and program goals must be somewhat configuration-oriented and advisedly directed toward achieving scheduled field objectives. For this reason, all R&D

TABLE AE–A
UNMASTERED AERODYNAMICS PHENOMENA

FLUID MECHANICS	• Trailing vortex wake of rotor blades • Stall and separation phenomena of rotor blades • Aerodynamic interference between rotating blades and other components
DYNAMICS	• Dynamic stability of highly coupled aeroelastic multi-degree of freedom systems
FLIGHT CONTROL	• Determination of overall handling qualities and control response characteristics
ACOUSTICS	• Noise phenomena of fluctuation pressures

activities in aerodynamics have been categorized under the subdisciplines listed as in table AE–B.

Within each major discipline area, quantified achievement estimates have been established as presented in chart AE–I (located at the end of this section). Incremental achievement goals are shown for the 20-year span covered by the Plan with application on near-term, mid-term, and future airmobile systems.

It should be borne in mind that there is considerable interdependence, not only among the various categories addressed in aerodynamics, but also among the various disciplines discussed separately in this document.

FLUID MECHANICS

GENERAL

In recognition of the growing importance of rotors in aeronautics, numerous techniques have been advanced for describing the flow through the rotor disc and for predicting blade airloads and performance. The aerodynamic phenomena listed in table AE–A are representative of the factors that contribute to the complexity of this flow field. Reliable calculations of the influence of these phenomena on blade airloads are essential, not only for assessing the effects of parametric changes on the performance of Army aircraft, but for defining valid operational limits, establishing structural and propulsion requirements, and making realistic tradeoff analyses.

Although recent evaluations of state-of-the-art methods for predicting rotor loads and vibrations show significant improvements in accuracy and reliability, these methodologies do not yet meet the demands of modern Army aviation. Global aerodynamic characteristics of conventional helicopters, such as overall rotor lift, drag, and power requirements, can be estimated reasonably well, but not the blade-element or component airloads that contribute to stresses, vibrations, and aeroelastic instabilities. Also, the ability to predict some of the global characteristics of many advanced configurations remains suspect. Improvements are, therefore, needed. Additional needs include an examination of the existing methods for the sources of the deficiencies and an estimation of the degree of sophistication and rigor that will ultimately be required to model correctly the rotor wake, boundary layer, and separated flow regions. These phases of research might include specially designed experiments to verify model authenticity. The overall intent of such an investigation is two-fold: first, to provide the design engineer with reliable bounds on the utility and applicability of existing prediction techniques; and second, to disclose areas of weakness that require further theoretical development.

UNSTEADY AERODYNAMICS

Rotor Flow Field. The trailing vortex wake of the rotor blades consists of a spiraling tip vortex filament and a trailing-edge sheet of vorticity from each blade. The trajectories and induced velocity contributions of these elements of vorticity are much more complex for rotorcraft than for fixed-wing aircraft, because each blade executes a combined translational and rotational motion in space, undergoes cyclic changes in pitch, and experiences elastic torsional and flapping motions. Furthermore, the trailing vortex wake becomes skewed and further complicated by all of the local variations in blade-element conditions. Performance, vibratory airloads, aeroelastic interactions,

TABLE AE–B

AERODYNAMICS SUBDISCIPLINE DESCRIPTION

FLUID MECHANICS	• PERFORMANCE Prediction and improvement of aircraft flight capacities, including hover, rates of climb, cruise and maximum flight speeds, autorotation, and maneuvering flight load factors • UNSTEADY AERODYNAMICS Prediction and reduction of vibratory airloads of aircraft components, including blade stresses, control loads, and aerodynamic excitation of noise, vibration, and structural dynamics. • EFFICIENCY Prediction and improvement of aerodynamic drag characteristics, including power requirements in hover and forward flight, fuel consumption, and payload fractions.
DYNAMICS	• AEROMECHANICAL STABILITY Pertains to the prediction of stability characteristics of the coupled rotor-fuselage dynamic system under the influence of self excited aerodynamic, elastic and inertial forces. • AIRCRAFT VIBRATION Pertains to the prediction of structural response of the aircraft due to aerodynamic and inertial excitations, including means for reducing vibration with external devices or by tailoring structural properties. • ROTOR LOADS Pertains to the prediction of loads and stresses experienced by the rotor blades, hub, and control system.
FLIGHT CONTROL	• CONTROL THEORY Encompasses the theoretical techniques which provide the basic understanding, insight, and computational tools supporting flight control analysis. • CONTROL ELEMENTS Is concerned with development of components of the flight control system to make them less costly, lighter, more reliable, simpler to maintain while maintaining or improving performance. • STABILITY AND CONTROL Covers the information and tools required to support the flight control design synthesis process. Flight control requires significant inputs from the fluid mechanics and dynamics technologies. • HANDLING QUALITIES Describes the characteristics which define the pilot's ability to perform a given task and the workload involved. Stability and control and display characteristics are the primary factors of concern.
ACOUSTICS	• AERODYNAMIC NOISE CONTROL Pertains to the prediction and alleviation of external and internal noise levels produced by: Impulsive waves originating on rotor blades and propellors Strong interactions between the rotor's wake (tip vortices) Inflows turbulence and local blade stall Also pertains to methods of reducing the adverse effects of noise through: Flight path control Development of quantitative detection criteria. • INTERNAL NOISE Pertains to those methods of isolating the crew and passengers from the noise levels of operational helicopters.

and noise are extremely sensitive to the details of this vortex wake. Existing analyses are particularly deficient in this regard and need to be improved.

One of the most promising areas for reducing the vibratory airloads and noise associated with the nonuniform, unsteady vortex wake involves the reduction of the peak velocities within the tip vortex. This might be done by changes in the planform or twist of the rotor blades in the tip regions, or by devices that alter the formation and structure of the trailing vortices. Such devices are also being considered for alleviating the vortex wake of large, fixed-wing aircraft. Vibratory aerodynamic loads may be reduced by actively controlling the blade pitch angle through higher harmonic control, or by actively controlling the blade lift, using circulation control concepts. These methods attempt to compensate directly for the large velocity variations and nonuniformities in the wake experienced by rotor blades in forward flight.

Rotor Blade Stall. Boundary-layer separation and stall have a major impact on both performance and vibrations of rotary-wing aircraft. Classical, thin boundary-layer theories with relatively mild inviscid interactions must be broadened from fixed-wing technology to rotary-wing application. New criteria accounting for unsteady turbulent effects, dynamic separation boundaries, and viscous reversed flow regions must be investigated and developed. Beyond this, assessment of large regions of detached flow must be made, since the complete stall and reattachment process impacts on rotor performance. Additionally, moment stall, lift stall, and reattachment must be included as separate dynamic events, with each representing important forcing functions on the aeroelastic behavior of the rotor in forward flight.

Unsteady aerodynamic effects have been shown to produce stall delay, thereby increasing the maximum lift coefficient above that for static stall. However, this favorable characteristic may be accomplished by negative aerodynamic damping during this pitch oscillation through stall. This negative damping is caused by a hysteresis in the blade pitching moment as the angle-of-attack cycle is closed, which can cause dangerously large torsional blade deflections and correspondingly large control loads. This event currently represents a major design limitation of some rotary-wing aircraft, restricting flight speeds to values below available engine power and below the allowable limits of other constraints.

Considerable improvements in estimates of rotor vibratory airloads have been made in recent years by applying empirical corrections derived from oscillating airfoil tests to the static stall characteristics of rotor airfoils. Often, however, predictions are still unsatisfactory, and some of the fundamental mechanisms of dynamic stall, especially in the three-dimensional rotor environment, remain essentially unknown. An important feature has been found to be the shedding of a vortex-like disturbance from the leading edge region. Current assessments indicate that this phenomenon can and should be studied in greater detail to provide complete documentation of select cases for guiding and evaluating future theoretical developments.

Once the mechanisms responsible for separation and leading-edge vortex shedding during dynamic stall have been identified, the potential of both static and powered boundary-layer control devices should be investigated. It is conceivable that properly designed fixes on the rotor could delay the onset of separation or sensibly soften the effects of moment and lift stall, thereby reducing vibratory control loads and improving performance, stability and controllability.

Advanced Blade Tips. Flow models and numerical analysis are both required for inviscid flow investigation at the tip regions of rotor blades. At this locations, transonic effects, tip vortex formation, and initial rollup add to the complexities of the highly three-dimensional flow field and often result in disproportionate increases in vibration and rotor power. Existing methods seldom predict correctly either the indiced drag or the profile drag in the tip regions of highly loaded rotors, resulting in errors in performance calculations. Improved inviscid analyses will provide boundary conditions for the viscous flow, the near-field trailing vortex field for assessment of blade-vortex interactions, and a rational basis for tradeoff optimization of tip shapes with respect to drag and noise.

PERFORMANCE

Advanced Airfoil Section. The need for improved rotor system performance in conjunction with advancements in airfoil technology, design, and manufacturing methods has resulted in the proposed use of several new airfoil shapes. A program is required to obtain and catalog the aerodynamic characteristics of

those airfoils that specifically show potential application to rotary-wing vehicles. The data accumulation must be on such a basis as to provide the rotary-wing designer with comparative data on the various shapes and should include the effects on rotor performance and wake geometry of camber, twist aspect ratio, variable geometry, leading edge radius, trailiing edge reflex angle, tip shape, and blade number. In addition, the range of test conditions should reflect Reynolds number, advance ratio, and reduced frequency variations. There should be a strong guidance and evaluation interplay between this investigation and theory, and the latest developments in unsteady aerodynamics and dynamic stall should be incorporated into the design of new airfoils.

Aerodynamic Drag. Vehicle shapes have largely been a matter of empirical design, primarily because of an inadequate understanding of rotor flow field. Without experiment, vehicle drag predictions can be in error by as much as 50 percent. Estimates of rotor form drag are also deficient because of inaccurate assessments of compressible effects and boundary-layer separation. As configuration size and complexity increase, methods that realistically account for rotor wake and fuselage interactions will become crucial in determining hover power requirements. Methods to predict hub drag, which typically comprises over 30 percent of aircraft flat plate drag in forward flight, are likewise important for accurate predictions of power required and maximum speed.

An increasingly important aspect of excessive aerodynamic drag is the awareness that it represents wasted energy. Recent studies indicate that significant reductions in fuel consumption of contemporary helicopters could be achieved by reducing hub drag, separation-induced pressure drag on the helicopter fuselage, form drag on external protuberances, and drag due to unfavorable interference between the main rotor and other components of the aircraft.

Aerodynamic Interference. Complex interactions between rotor wakes and fuselages (or between separate rotor wakes) produce undesirable vibrations and adversely affect aircraft lift and drag, thereby degrading performance. Flow interference can also introduce extraneous forces on the aircraft, thereby affecting the stability handling characteristics. Still another problem is the loss in yaw control that can occur when the wakes of the main rotor pass through the tail rotor. Recent studies have led to relatively simple modifications to existing aircraft, such as reversing the direction of rotation of the tail rotor. This technique was used to partially alleviate severe problems that were being encountered by operational aircraft. A search for a better fundamental understanding of the phenomenon should be continued and a more efficient configuration established.

EFFICIENCY

Prediction Procedures. The increasing spiral in aircraft size, sophistication, and cost (as well as the projected efficiency and cruise-speed trends shown in figures AE–1 and AE–2) place great importance on the ability of the designer to define accurately performance and tradeoff limits of a system in early conceptual studies. The viability of a particular system could hinge on such an analysis. Available prediction techniques are considered unsatisfactory for this task and could result in erroneous estimates, cost and performance, which could initiate the departures from existing sensible designs.

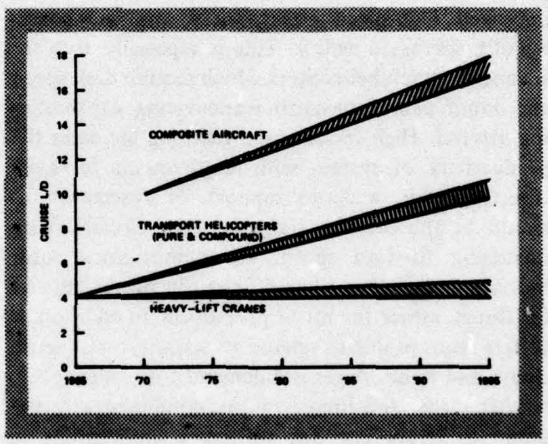


Figure AE–1. Aerodynamic efficiency trend.

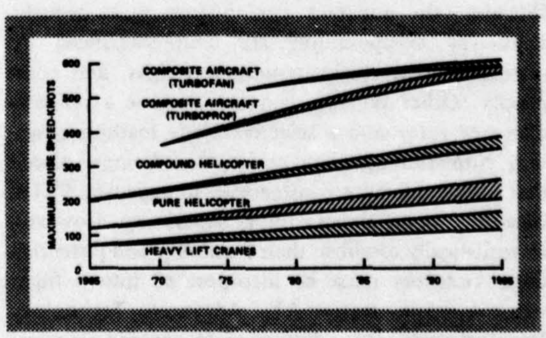


Figure AE–2. Cruise speed trend.

Considerable effort is needed in a comprehensive analytical treatment of the rotor flow field. Care must be taken to avoid building a theoretical model from unproven fragments or of unwarranted complexity. Specifically, initial attempts should be focused on describing a two-dimensional airfoil that oscillates through stall, thus encompassing unsteady laminar and turbulent boundary-layer effects, regions of separation, and viscous-inviscid interactions. With the assurance of experimentally demonstrated reliability, attaining this level of analytical competence alone would qualify as a major contribution. Other phases should address more complicated three-dimensional flows, such as would exist on rotating finite-span airfoils.

Configuration Optimization. Specialized areas of research must be integrated so that resulting criteria can be used in optimizing the overall V/STOL configuration for specific mission requirements. For example, all airmobile systems would benefit from improved high-speed effectiveness, and the consequently increased agility. This is especially true for advanced attack helicopters which require dash speed and rapid nap-of-the-earth maneuvering capabilities for survival. High cruise speed tailoring increases the productivity of system with requirements for swift troop delivery, weapons support, or evacuation, as would be the case for transport type aircraft. With increasing forward speed, the conventional rotor becomes progressively less efficient in producing useful thrust, either for lift or propulsion. In addition, it suffers from problems related to stability, gust sensitivity, and noise. A general demand for higher speed, heavier loads, and longer ranges, combined with the desire to retain low disc loading characteristics in hover, has encouraged the development of compound vehicles. By adding a fixed or pivoted-wing, the forward flight lift requirement of the rotor is relieved. However, the apparent performance gains brought about by compounding are counterbalanced by increased initial costs, structural weight, and complexity. Other possible concepts include a variable-diameter rotor and a selective blade feathering system. Numerous advanced concepts are being explored that may contribute considerably to improved VTOL versatility in achieving combat superiority. However, to realistically establish their feasibility and potential, these concepts must be incorporated into a flight vehicle. See section AT, Advanced Technology Demonstration, for a discussion of ongoing programs that fall within this category.

Supplementary Aero Devices. Another important area of aerodynamics research relates to the addition of supplementary static and power-augmented control, lift, and propulsion devices. Various performance-increasing techniques including drooped leading edges, slots and slats, and numerous types of flap arrangements have been applied to fixed-wing geometries. These methods depend solely on free-stream energy diversion and have met with considerable success. Alternate systems have been designed to convert propulsive exhaust energy into useful lift and control energy. The benefits of a compound configuration employing assorted types of variable geometry fixed and pivoted wings, with and without additional blowing and thrust diverting devices, need to be investigated. The program should include techniques for predicting the performance and stability characteristics of these systems in order to establish their feasibility before proceeding with technology demonstrations.

FLUID MECHANICS TOPICS SUMMARY

The various research topics discussed under fluid mechanics can be categorized as listed in chart AE–II, with interrelationship between the topics shown by the accompanying matrix. Should each of the areas

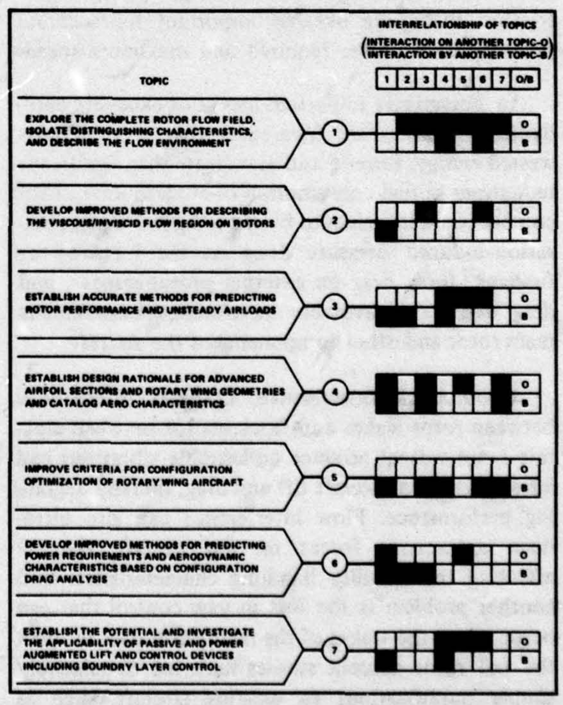


Chart AE–II. Fluid Mechanics Topics Summary

be adopted as an element of a unified research program, the quantified achievement goals indicated in chart AE–I could be attained.

DYNAMICS

GENERAL

The importance of having a thorough and comprehensive understanding of the dynamic characteristics of aircraft in general and helicopters in particular has been appreciated in varying degrees by designers for some time. It has long been realized that in the design of rotary-wing aircraft, dynamic characteristics can determine the fate of the aircraft. Unfortunately, however, in several instances the importance of dynamics in Army aircraft has been recognized too late in the design process and finding the required solution to the resulting problems has been extremely costly. In other instances, the problem may be recognized but the limitations of today's state-of-the-art force the designer to place operational constraints on the aircraft rather than provide a design solution that would remove the problem from the aircraft's originally intended flight envelope. For example, almost without exception, the limiting factor on the top speed of helicopters is not an installed power limitation, but excessively high vibratory loads that increase with forward speed. Coupling the significant role dynamics plays in the design of rotary-wing aircraft with the fact that the inventory of Army aircraft is largely rotary wing, it becomes obvious that consideration of aircraft dynamics in the formulation of an Army air mobility research and development program is of highest import.

Recognition of the importance of and the need for dynamics research for the development of improved Army aircraft is the first step in establishing a viable plan for executing that research. The next step is recognizing and appreciating the tremendous complexity of the problem. Figure AE–3 represents the dynamics design problem that includes all the elements of the rotorcraft including the pilot and control system. As indicated, the rotor blades are elastic members and have many coupled modes within themselves. They, in turn, are attached, through flexible linkages and a flexible swashplate, to the remainder of the structure, which is represented by a series of elastically coupled lumped masses. All the degrees of freedom shown are excited continuously by periodic inertial forces and by complex aerodynamic loadings, represented in the figure by the hammer.

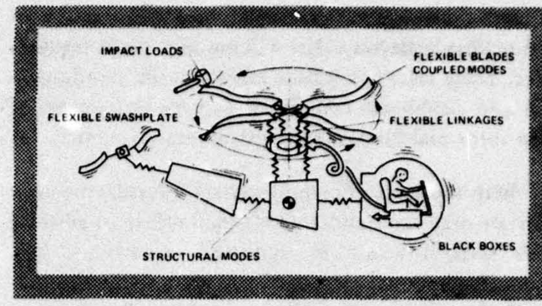


Figure AE–3. Dynamics complexity.

From this figure it is obvious that the dynamic problem is strongly coupled with other technologies, particularly materials, structures, and aerodynamics. Recognizing that the dynamic problems involved relate to structural dynamics as opposed to rigid-body dynamics, the coupling with the structures and materials technology is immediately obvious. The origin of the forcing function in the problem, as well as some of the damping terms, is aerodynamic, thereby necessitating a close relationship between the aerodynamic and dynamic programs. These two technologies must progress together to advance the state-of-the-art of the dynamics considerations in rotary-wing design analyses. This necessarily combined advancement of technologies is illustrated in figure AE–4, which summarizes the present capability and what current efforts are expected to accomplish with respect to the capability to make combined aerodynamic-dynamic analyses. The first boundary in the figure represents a judgment of where current capabilities lie in terms of handling the combined aerodynamic and structural dynamic effects. The

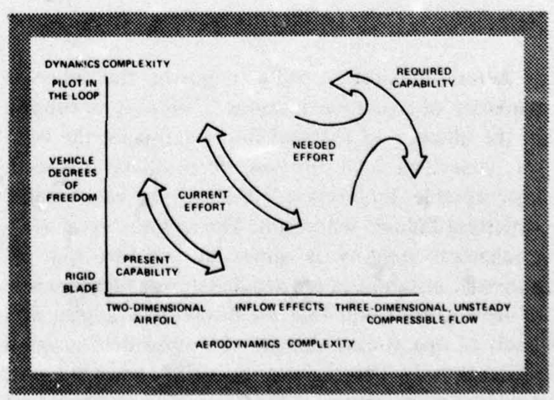


Figure AE–4. Aerodynamic and dynamic considerations required in design analysis.

second boundary indicates analytical and experimental studies underway that will improve these capabilities. These relate to inflow effects in the aerodynamics and rigid-body and elastic degrees of freedom of the rotor and fuselage in the structural dynamics.

With the level of complexity such as it is, the need for an organized and well-planned effort to advance the state-of-the-art in dynamics is obvious. Key factors related to each of the Army air mobility missions have been addressed in the Systems volume of this document. An inspection of these key factors reveals that there is not a direct relationship between any one factor and a basic science area such as dynamics. Rather, advances in dynamics impact in an indirect manner as, for example, with respect to low life-cycle cost, which is a primary factor in the UTTAS mission. Reduced life-cycle cost is a result of improved reliability and maintainability techniques and procedures. A significant factor in improved reliability and maintainability of rotary-wing vehicles is the alleviation of the dynamic loads inherent in these aircraft. The achievement of this objective is expected to be a direct consequence of the R&D effort presented in this portion of the plan and thus relates to the key factor of low life-cycle cost. In a similar way, the objectives of the R&D program in dynamics are related to each of the key factors shown.

The program presented herein is based on the three major areas that constitute rotorcraft dynamics: aeromechanical stability, aircraft vibration, and rotor loads. In the following discussion of each of these areas, a general description of the technology is given, subjects needing research are identified, and goals are defined for potential practical improvements of future helicopters.

AEROMECHANICAL STABILITY

Aeromechanical stability concerns the inherent tendency of structural motions to amplify or subside in the absence of external forces acting on the vehicle. Unless all such motions are positively damped, unacceptable limit cycle vibrations or catastrophic structural failures will result. The technology of aeromechanical stability is aimed at ensuring that all potential instabilities are avoided during development of new aircraft and that no instabilities appear as a result of operational changes or normal deterioration of the aircraft. This technology is also concerned with minimizing the adverse side-effects of techniques used to prevent instabilities. The research program in aeromechanical is oriented around several general objectives that include the following: developing and verifying analytical methods for predicting potential instabilities; defining and describing the behavior of complex rotor configurations with respect to the important system parameters; and identifying ways to eliminate instabilities or to minimize the adverse effects of eliminating them.

A basic class of instabilities concerns the dynamics of isolated rotor systems. Classical blade flutter is usually amenable to existing analytical techniques. A potential benefit in this area is a reduction of the weight penalty that is usually incurred by flutter prevention mass balancing. Another type of instability, involving the coupled pitch, flap, and lead-lag motions of the rotor blade, is especially important for hingeless rotor configurations. This phenomenon is dependent on a large number of rotor blade parameters and is not yet well understood. Stall flutter is another serious problem for many rotor types in high-speed, forward flight because it produces excessive vibratory loads that are transmitted into the rotor control system. Another type of rotor blade instability can be experienced at high rotor thrust conditions, in hover, for rotor configurations with a large number of blades. This phenomenon is associated with blade-vortex interactions and may be manifest as an out-of-track condition, a subharmonic limit-cycle oscillation, or a transient vibration. In high-speed, forward flight, articulated rotors have experienced difficulties that are mainly due to excessive rotor flapping sensitivity during maneuvers and operation in atmospheric turbulence. Compressibility effects on the advancing blade tips may produce erratic blade flapping behavior that can seriously affect the rotor control characteristics.

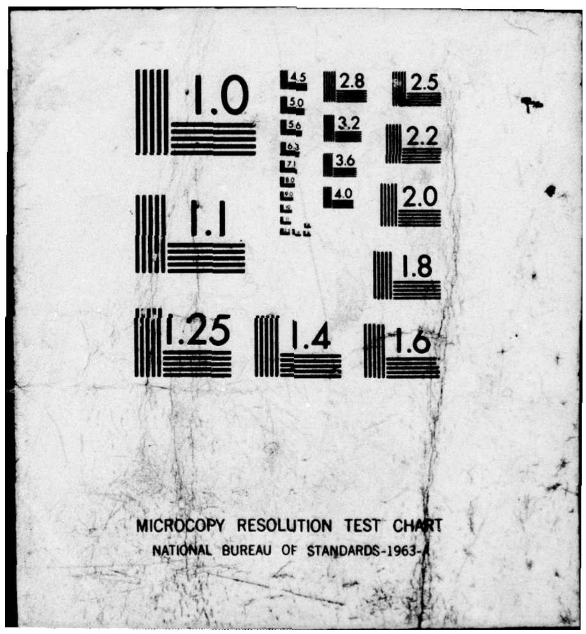
Another class of aeromechanical instability involves the coupling between the rotor and fuselage of the helicopter. Such phenomena as classical ground resonance fall into this category. More recently, similar instabilities have been discovered for hingeless rotor helicopters in flight; these are termed air resonance instabilities. In some instances, air resonance may also occur for tandem helicopter configurations. Coupled rotor-fuselage instabilities at high-speed, forward flight conditions are not yet well understood, especially for hingeless rotor helicopters.

Many other rotor instabilities may occur that are not easily categorized but can have important consequences. Rotor-blade instabilities may result from excessively flexible control systems where coupling between the fuselage structure and the rotor can take

AD-A035 334 ARMY AVIATION SYSTEMS COMMAND ST LOUIS MO F/G 1/3
ARMY AVIATION RDT AND E PLAN.(U)
OCT 76

UNCLASSIFIED NL

2 OF 4
AD
A035334


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

place. Other related examples are instabilities involving a feedback control system. These are particularly troublesome since they appear as a byproduct of an attempt to stabilize some other marginal dynamic characteristic of the helicopter – for example, a stability augmentation system intended to improve the vehicle flying qualities. A potential exists for nonlinear instabilities because the basic equations of motion of a helicopter rotor are nonlinear. For normal operating conditions, such systems may be stable, with no indication of potential difficulties. However, when a certain operating condition is exceeded, the system may become unstable. Other complex dynamic systems subject to instabilities are tail-rotor/fuselage systems and tilt-rotor aircraft; in both, a rotor is mounted at the extremity of a long flexible structure and the coupling of various rotor and structural modes may be responsible for very complex instabilities. A disturbed aerodynamic environment may also be an additional cause for difficulty in these cases.

The complexity of these dynamic problems, which can lead to very troublesome instabilities, places severe demands on dynamics technology. This become especially difficult when it is realized that the objective is to discover and prevent such occurrences before a prototype is developed. If a serious instability is discovered at this point, a major redesign of the dynamic system of the aircraft may be required. Because of the complexity of the dynamic problems, it is important to realize that several key ingredients are required in a long range plan of research. Without these, considerable efforts may be expended without meeting the required objectives. The key ingredients are related to one another and together will yield a detailed and comprehensive understanding of the dynamic phenomena that may cause instabilities of future aircraft. Without a basic and comprehensive understanding, potential instabilities will not be reliably predicted.

The key ingredients in the technological effort may be defined as various theoretical and experimental research efforts. First, the complex dynamic system must be broken down into smaller and simpler elements. Only at this level will the mathematical models be simple enough to interpret physically to permit a full understanding of the problem. In this way it is also possible to identify and isolate those essential physical parameters that govern the stability of the system. Second, when the basic elements of the system are sufficiently analyzed and understood, they may be combined to describe the complete system. This process depends on the successful completion of each of the individual stages in the analysis. Third, a continual experimental program must be pursued to validate the mathematical models and identify areas that are not being adequately predicted by theory.

Some of the specific areas of technology that need development and refinement are in the structural representation of rotary-wing systems and in the development of mathematical tools to handle nonlinear systems and equations with time-varying or periodic coefficients. Also important is the need to develop more accurate experimental techniques both for wind-tunnel models and full-scale aircraft. Improvement is needed in data analysis as well. The experimental measurements generally include random and periodic noise both from the experiment and the measurement process. The effects of this noise must be removed to determine the system stability, a task made more difficult when the experiment includes nonlinear or periodic effects.

One of the difficulties in math models of structural systems of rotary-wing vehicles is in accounting for all of the highly coupled and complicated degrees of freedom. The equations for a rotating beam undergoing large deflections are complicated by variable and discontinuous changes in mass properties, stiffness, and torsional rigidity, and they are in turn attached to flexible fuselage structures of considerable complexity. Because some choice has to be made in approximating these structures mathematically, a better understanding is needed of how these complex structures behave. At the present time, intelligent choices are difficult to make because of lack of experience with many systems. The special characteristics of new materials such as composites, must be accounted for, especially with respect to defining the structural damping, which may have a strong influence on stability.

The mathematical tools that need to be developed may be fairly well categorized by present knowledge of the basic characteristics of rotary-wing systems. Periodic-coefficient equations are typical for rotors in forward flight because of the oscillating aerodynamic forces acting on the blades. Floquet theory is useful for predicting the stability of these systems; however, little experience with this technique is available for problems with many degrees of freedom. The large structural deformations of rotor blades often make linear assumptions inappropriate and require new techniques for solving nonlinear equations. The

method of matched asymptotic expansions is a potentially powerful tool for many of these problems.

With the ability to generate a comprehensive understanding of the dynamics of complex rotary-wing systems, aeromechanical instabilities should not pose a threat to the successful development of new aircraft. Thus, it is feasible that all potential aeromechanical instabilities can be avoided and, further, that such instabilities would no longer impose constraints on the practical operational envelopes of rotary-wing aircraft, or incur unnecessary design compromises during development.

AIRCRAFT VIBRATION

Aircraft vibration is the response of the structure to periodic excitation forces. In the case of the helicopter, the response of interest is the fuselage structure, and the main excitation is provided by rotor forces applied at the rotor hub. These forces, in turn, represent the response of the rotor blades to periodic aerodynamic loading. The vibratory response of the fuselage structure is determined by the nature of the applied rotor forces and also the structural dynamic properties of the fuselage. The objective of research efforts is to develop techniques and methods for predicting and minimizing aircraft vibration.

As noted earlier, the limiting factor on a helicopter's maximum forward speed today is not installed power, but vibration level. Although it is known that unacceptably high vibration levels exist in some flight regimes, there is not a clear definition of the requirements for the vibration spectrum reduction. Obviously, the eventual goal is to eliminate vibration loads across the entire spectrum, but this will not take place in one quantum step and it is important that we define those portions of the vibration spectrum that, when reduced or eliminated, will provide the largest payoff in terms of weight and performance. When it has been firmly established what the requirements are, it will become clearer what methods should be pursued in attempting to satisfy them. To date several approaches have been followed. These include methods to detune the vehicle structure to minimize response to periodic aerodynamic loads, development of active or passive devices to isolate ot absorb vibratory loads, and investigations aimed at reducing the periodic aerodynamic loading on the rotor.

The periodic aerodynamic loadings arise from unsteady aerodynamics, airfoil dynamic stall characteristics, blade-vortex interactions, and the basic periodic velocity variation experienced by the rotor blade in forward flight. Research efforts aimed at reducing these loadings can be expected to alleviate some of the vibratory load problems on rotary-wing aircraft. Improvements in the dynamic stall characteristics of airfoils and minimization of the tip vortex velocity are probably the most promising areas for reducing these aerodynamic inputs. Other potential methods for reducing periodic aerodynamic loads may result from active control of the blade pitch angle through higher harmonic control, or of the blade lift using circulation control. These methods attempt to compensate directly for the large velocity variations and for the nonuniform-induced velocities experienced by the rotor blade in forward flight.

The traditional method for reducing aircraft vibrations is to design the structure so that natural frequencies are not placed in proximity to the fundamental aerodynamic forcing frequencies. This tuning procedure is only as successful as the accuracy of methods used to predict the natural frequencies of the structure and these techniques have never been completely reliable for rotary-wing aircraft. The use of advanced composite materials holds promise for tailoring the structure to a much higher degree than was previously possible with conventional materials. This then allows greater potential for tuning the structure to avoid the aerodynamic forcing frequencies, but, in turn, increases the accuracy requirement in the structural modeling methods. As is true for the analysis of aeromechanical instabilities, a successful solution to the structural dynamic approach to vibration reduction must rely on a more comprehensive understanding of the fundamental elements of the problem. This entails mathematical modeling of simplified structures, experimental efforts to augment those analyses, and an integrated approach to treating the entire problem.

An effective method of dealing with vibration problems in the past, especially in view of the complexity of the structural dynamics of the complete system, has been to attempt to suppress the transmission of specific vibratory inputs or the vibratory response at specific locations. Thus, a whole series of techniques and devices has been investigated and applied to helicopters with substantial success. These devices or methods may involve active or passive means and are usually characterized by a very narrow range of effectiveness; that is, a particular vibration absorber may be well suited to one type of rotary-wing aircraft but relatively ineffective on another. In view of the inherent difficulties in the methods discussed previously, the use of vibration isolator

systems deserves continued attention, even if only as an interim solution. Efforts should be made to improve their effectiveness while reducing the attendant weight penalty and increasing the mechanical reliability.

ROTOR LOADS

Rotor loads are considered to include the dynamic loads and stresses existing in the rotor blades and blade pitch control mechanisms. Together, vibratory response and rotor loads usually determine the limiting speed and load factor operational envelope. Furthermore, the rotor loads determine the fatigue life and reliability of rotor system components. The calculation of rotor system loads is one of the most difficult analytical problems of rotorcraft technology because of the importance of nonlinear, unsteady, three-dimensional, compressible aerodynamics, and the complexity of the structural dynamic characteristics of nonuniform rotor blades. The objectives of this area of research are to improve methods for predicting rotor loads and to find ways of reducing rotor loads. The benefits of reduced rotor loads are clear: component life will be increased and costs reduced. Better prediction of rotor loads will permit correspondingly better predictions of aircraft vibration and will facilitate future reduction in vibration levels. The present inaccuracies in predicting rotor loads require overly conservative safety factors in the design of rotor hub and control system components. More accurate prediction will result in more efficient structural design and significant savings in weight.

The technology for predicting rotor loads is still being developed. The problem can be broken into three basic areas: aerodynamics, structural dynamics, and mathematical analysis techniques. The aerodynamic technology, particularly in the case of complex phenomena such as dynamic stall and blade-vortex interactions, is being pursued as part of the fluid dynamics program. The structural dynamics technology involves the description of the elastic and inertial properties of a rotor blade, including the details of the nonuniform, twisted, composite structure. Consideration must also be given to nonlinearities associated with large displacements that occur during extreme operating conditions. Finally, improvements are needed in the mathematical methods used to solve these highly coupled, nonlinear equations. The accuracy of the solutions needs to be improved and computer time requirements need to be reduced. Until these numerical solutions can be produced at moderate cost, they will only be of limited value to rotorcraft designers. Because of the complex interdisciplinary nature of rotor loads prediction methods, it is difficult to validate their accuracy and determine specific elements that require improvement. Special attention is required to devise techniques for validating the various elements individually, and additional wind tunnel tests of full-scale rotors are needed to determine the accuracy of the final results.

As the accuracy of rotor loads predictions is improved, it will become increasingly practical to use these methods to reduce rotor loads by properly tailoring the structural and aerodynamic properties of the blade. For example, torsional stiffness of the blade has been shown to influence stall flutter and the consequent control system pitch link loads. Other techniques and devices should be investigated to reduce rotor loads. Because of the close relationship between rotor loads and aircraft vibration, efforts in these two areas will necessarily be dependent on each other.

DYNAMICS TOPICS SUMMARY

The various research topics discussed under dynamics can be categorized as listed in chart AE–III, with interrelationship between the topics shown by the accompanying matrix. Should each of the areas be adopted as an element of a unified research program, the quantified achievement goals indicated in chart AE–I could be attained.

FLIGHT CONTROL

GENERAL

Superior levels of maneuverability, speed, payload, structural integrity and reliability are of little use if poor flying qualities limit their application. The ultimate objective is to be able to make full use of all the inherent capabilities, that is, to be able to fly to the limits of the service flight envelope under all the desired environmental conditions (wind, turbulence, day, night, limited visibility). There is little doubt that almost any objective can be achieved at a cost. An intractable aircraft, with plenty of control power, can be made well behaved using the flight control system and black boxes. Unfortunately this is usually an expensive and unreliable approach. The real question is what are the minimums? How should initial design characteristics be traded-off with flight control system complexity, or, given a design, what is the minimum necessary flight control system? The answer is a tradeoff between pilot workload, training

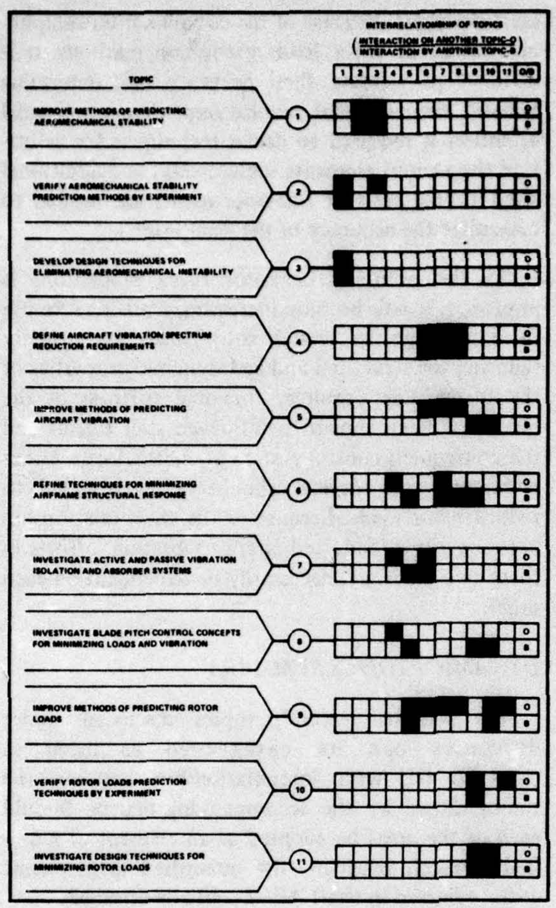


Chart AE–III. Dynamics Topics Summary

requirements, mission effectiveness, cost, complexity, and reliability. It may not be cost-effective to design to the minimum requirements. For example, if two aircraft were to perform the same tasks, a small, cheap, simple aircraft used in large numbers would require quite different compromises than a large expensive complex aircraft that is used in much smaller numbers. In the simple aircraft, pilot proficiency in flying will be relatively cheap, whereas it may be prohibitively expensive in the complex aircraft. Ideally, the answer to this problem is to obtain systematic information on the ability to perform a task as a function of stability and control characteristics, and display requirements for control and navigation and guidance. Then, the designer can perform a tradeoff to obtain the most cost effective compromise in achieving these design goals for a particular application.

Having established design goals, there are two other problems: prediction and evaluation. All V/STOL aircraft configurations have complex flight control problems, such as stabilization requirements, control phasing, large power effects, etc. However, rotary-wing aircraft are particularly complex because of the complicated aerodynamics and dynamics of the rotor. The result is a difficulty in predicting the stability and control characteristics during design, and determining what the characteristics really are when the helicopter is actually built. Overall design goals and evaluation capabilities are the primary topics in this subsection; prediction is treated primarily in the previous subsections. Figure AE–5 is a block diagram of the closed loop pilot-aircraft system and shows the interdependence of aerodynamics, dynamics, and flight control.

In addition to the development of design goals, prediction, and evaluation capability, it is important that practicality is demonstrated through hardware development. Everything from individual components, such as fluidic rate sensors and complete fly-by-wire control systems, to aircraft systems such as ABC, tilt rotor, and RSRA need developing. Only then are the real problems in a concept uncovered in a timely manner prior to production commitment.

Flight control is defined as the science and art of stabilizing and controlling the motion of a flight vehicle along a desired path. It comprises the items. topics, and objectives shown on figure AE–6. The first four topics (control theory, control elements, stability and control, and handling qualities) have been chosen as the major subdisciplines. There is, of course, considerable interdependence and overlap between these topics, so to minimize repetition, subjects that are not clearly in one of the first three categories have been discussed under handling qualities.

In the following major topic sections, the Plan describes the needs, and presents the background and perspective to each of the problem areas. Chart AE–IV summarizes the overall objectives of flight control, and outlines the technological goals that can lead to achieving these ends. The components of this total plan are presented and discussed in the following paragraphs.

CONTROL THEORY

Optimal Control. In recent years, considerable effort has been expended in the development and refinement of techniques in the field of optimal control theory. Such techniques provide a potentially

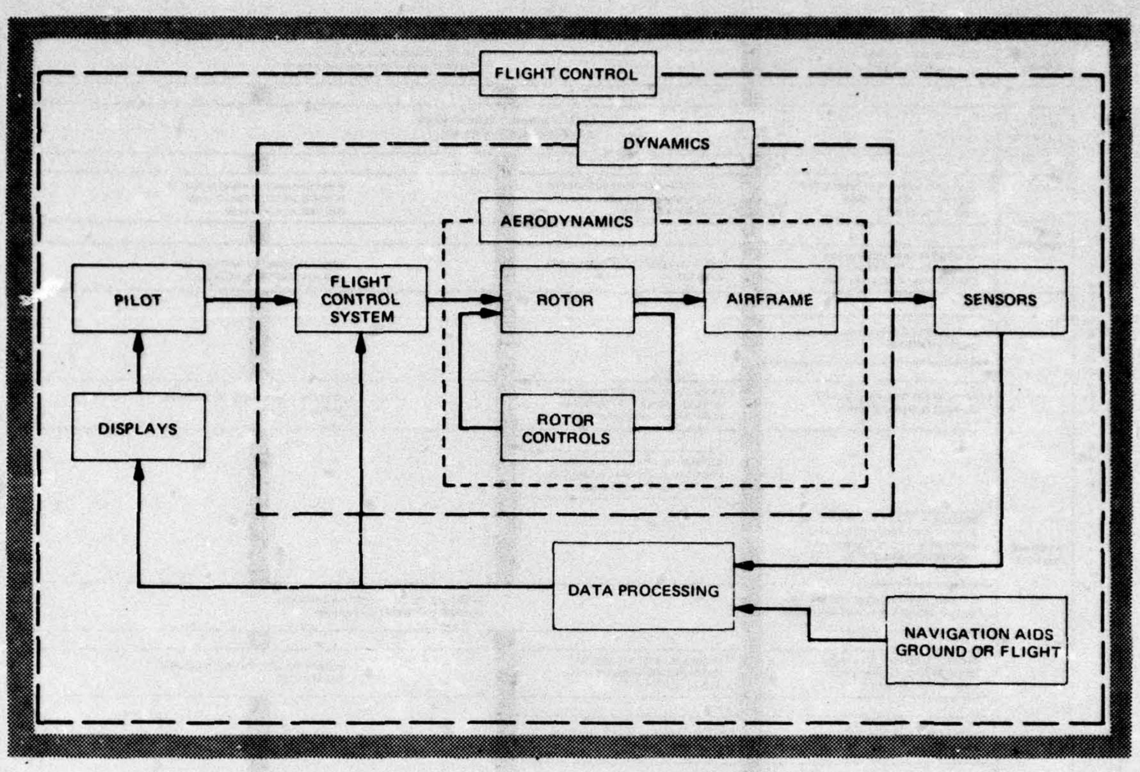


Figure AE–5. Interdependence of aerodynamics, dynamics and flight control.

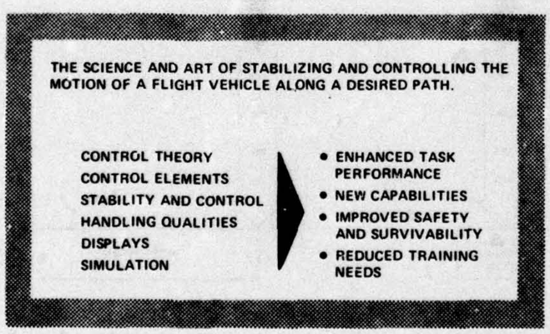


Figure AE–6. Flight control.

useful and orderly process for the design of control systems, especially for multiple input/output systems. With any technique however, the system is only optimal for a particular configuration, relative to a particular performance criterion. More work is required to investigate and define the performance criteria, and more work is required to assess the effects of those nonideal characteristics always found in real applications (e.g., measurement noise, plant unknowns, etc.).

Applications of optimal control can conveniently be divided into two aspects: control and guidance. Control aspects are typified by control phasing or blending to give a desired or tailored response. Guidance aspects are typified by determining flight paths to minimize fuel usage or noise exposure. These two will be discussed separately.

Control System Design. Given a well-defined aircraft with adequate control over each degree of freedom, the modern control theoretician can easily calculate the control gearings, control interconnects, and control feedback quantities to obtain any desired response. Unfortunately, real applications do not have all the ideal ingredients. For example, the ability to tailor responses suggests making them unlike an aircraft. The Tactical Aircraft Guidance System (TAGS) system is an example, where a step input to the longitudinal control commands a new speed rather than an attitude or attitude-rate. This sounds highly desirable, but there are an infinity of ways in which the new velocity can be achieved (e.g., a severe initial attitude change to get a large initial translational acceleration, followed by a gradual bleedoff as the desired speed is approached, or an attitude change only large enough to sustain the final velocity. In the latter case, the speed change may take too long and

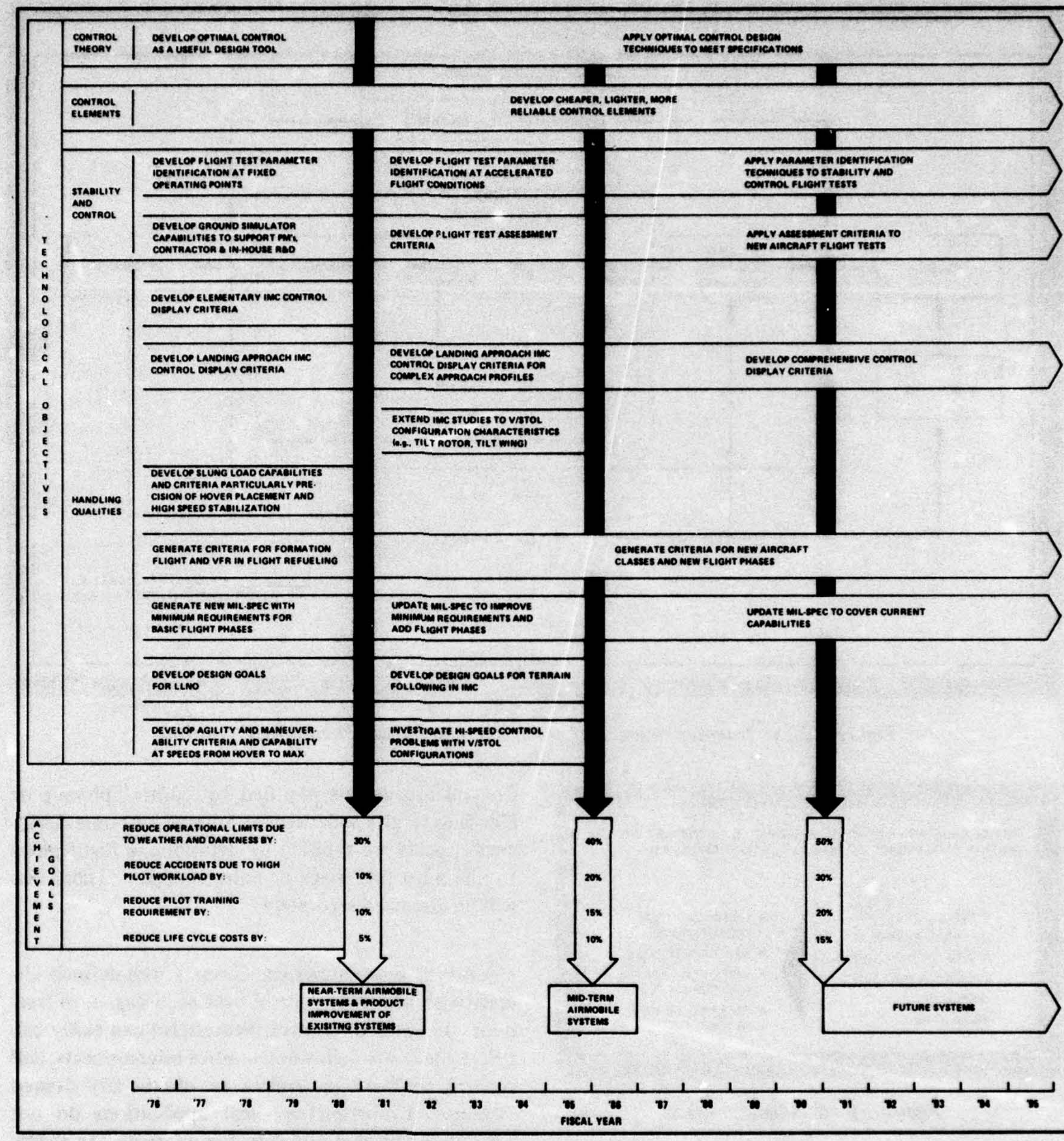


Chart AE–IV. Flight Control Objectives Summary and Achievements

the pilot may have to overdrive). There is need to obtain a better understanding of just what response is suitable for a given task. Ground simulation with simple models is the approach needed here.

The next problem is to achieve these desired responses on nonideal aircraft. The aircraft will be poorly identified (prediction and evaluation), there will be limited control authority and insufficient control over some degrees of freedom, some states will not be measurable, the sensors that are available will be noisy, and the aircraft will have to fly in turbulence. These are the problems that the control theoretician must solve to convert his theories into useful tools for the control system designer. It is important that work be continued and expanded in this area, with the emphasis always on solving the practical problems, not developing new theories.

Guidance Analysis. The second aspect, guidance, requires inputs from the tactician: How does he want to use his aircraft? To minimize fuel usage during

climb, descent, and loiter? To maximize over-obstacle capability? To minimize noise propagation? To minimize exposure to ground fire when approaching a forward landing site? Again, the ideal must be tempered by the realistic; optimum trajectories may not be flyable by the pilot, or may require complex flight-director aids. Since the real pertinence of this work is specific to a particular aircraft and mission, it should be performed at the advanced development (or higher) level in support of a particular system, i.e., flight path optimization considerations must be part of the control system design tradeoff pertaining to display-pilot workload/training.

Control Theory Summary. The research topics discussed under control theory may be summarized as follows:

- Perform piloted ground simulations to determine desired control laws
- Develop optimal control design techniques for non-ideal plants
- Apply developed optimal design techniques to specific aircraft and missions
- Verify with piloted simulation and flight test

CONTROL ELEMENTS

General. The flight control system provides an interface between the pilot and the airframe. A primary component within this interface is the rotor. Thus, the control system designer must be aware of, and accommodate the needs of, both the dynamics and the flying qualities specialists. Figure AE–5 shows that the control system is as much a part of "dynamics" as it is of "flight control." The brunt of "control elements" is hardware – the development of control system elements, from concept to field application, with the objective of making them cheaper, lighter, more reliable and simpler to maintain, while maintaining or improving performance.

Fly-By-Wire. Initial dependence on pure mechanical systems is giving way to the inclusion of hydromechanical, electromechanical, electronic, fluidic, and optical devices. As aircraft size increases, the potential weight saving in an electronic or optical control system (fly-by-wire) becomes greater. The feasibility of fly-by-wire (FBW) has been demonstrated in several Air Force programs as well as in the Army TAGS program, and the HLH demonstrator. Another potential advantage of FBW is survivability. The redundancy requirements and lightweight connector routings offer potential advantages in survivability from battle damage. This may be particularly applicable to AAH and ASH roles.

Sensors. A program to develop the application of fluidic devices to augmentation systems, using hydraulic fluid as the working medium, has now reached the stage of field demonstration and the potential of high reliability with low cost seems to be realizable. Improvements in sensor designs have significant cost savings potential. For example, many guidance and control systems, particularly those that are self-contained in the aircraft rather than ground aided, need ground referenced position information. Unfortunately, gyro inertial system are expensive and the gyros have short life in the typical helicopter vibration environment; perhaps the emerging Laser Inertial Navigation System (LINS) will lead to significant cost and reliability improvement. All helicopter roles have as a major flight phase the ability to maintain hover over a spot in a wind. In the case of the HLH, this even includes precise hovering over a translating ship. This task requires a form of "ground" speed sensor to provide the pilot with an accurate position reference, or to provide automatic coupling. A simple electronic, fluidic, or optical device that can provide this information would have great benefits.

Auxiliary Controls. As helicopters increase in size, or the demands for speed and manuverability increase, the concept of new or additional force and moment producing devices arises. Usually this is in the context of performance (speed and payload). However, there are possible advantages to be gained for control. The ability of a very large helicopter to perform precision slung load placement in hover may be considerably enhanced by incorporating an auxiliary thrust vectoring capability. Similarly, an advanced attack or scout helicopter may be able to follow terrain more intimately if thrust vectoring could be used to reduce rotor and fuselage tilt angles when maneuvering. More exploratory studies should be funded to encourage innovation by contractors.

Control Elements Summary. The development of a complete flight control system tends to be expensive. The final product is as much a function of the ingenuity of the designer who implemented the idea as it is of the idea itself. Much of the work is in solving the details of the particular application rather than the

basic concept. Because of this, control system development must be very carefully directed; it must either be kept simple or directed at a known requirement for a well defined system. Figure AE–7 summarizes the rationale for developing control elements.

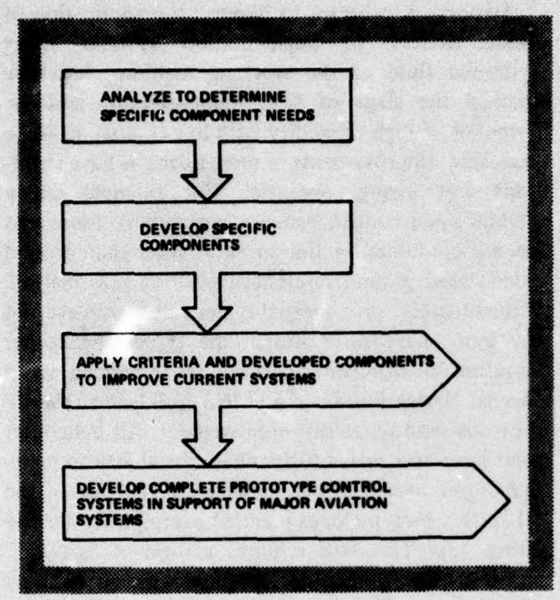


Figure AE–7. Control elements development cycle.

STABILITY AND CONTROL

General. To describe the work needed in stability and control and handling qualities, it is first necessary to discuss how the results of such work are used.

The design of an aircraft involves four basic functions:

- *Design goals:* It must be possible to define the characteristics that are desirable to design into the vehicle.
- *Synthesis techniques:* It must be possible to synthesize a configuration that will achieve the design goals.
- *Prediction capabilities:* It must be possible to predict the characteristics of the proposed configuration.
- *Design evaluation:* It must be possible to evaluate the predicted characteristics against the goals.

The actual design process is a continuing series of iterations, matching goals against capabilities. If stability and control are considered as encompassing the tools required to perform these iterative design loops, the block diagram, figure AE–8, can be used to define the areas of stability and control that need research. Design goals, i.e., criteria development, will be discussed in the subsection on handling qualities. Capabilities of analytical and wind-tunnel prediction of stability and control characteristics are covered in the aerodynamics and dynamics subsections. This leaves the capabilities related to ground and flight simulation, parameter identification, and flight test evaluation.

Mathematical Modeling. An essential part of stability and control work is the mathematical model. The form of model depends on the intended use, and can vary all the way from full global representation of all the known nonlinearities, boundaries, etc., appropriate to design assessment in the design loop (figure AE–8) to simple, decoupled linearized, small perturbation models, which are useful for analyzing and understanding stability and control aspects of flying qualities studies. One badly needed area of work is to take the best available representations of current Army helicopters and simplify them to the minimum number of parameters necessary for stability and control analysis. Specifically, determine the extent to which longitudinal and lateral-directional cross coupling, and rotor dynamics have to be included, and how this should be done (e.g., for the rotor, is a first-order representation sufficient or is a second- or higher-order representation required?). No doubt a different model will be required for different helicopters (e.g., single, multi, and teetering or hingeless rotor, etc.), but these baseline characteristics must be defined to guide future generalized handling qualities research.

Wind Shear and Turbulence. The way turbulence is modeled, and its intensity, has a very strong impact on flying qualities simulations. Atmospheric turbulence at a fixed point varies with time, and at a particular time it varies from point to point, i.e., it is time variant and space variant. For conventional aircraft, the speed is such that the time variations can be assumed negligible compared with the spatial variations. This assumption simplifies modeling, and is the basis for the most widely used models (e.g., that associated with MIL–F–8785B). However, this model is of questionable validty at low speeds and

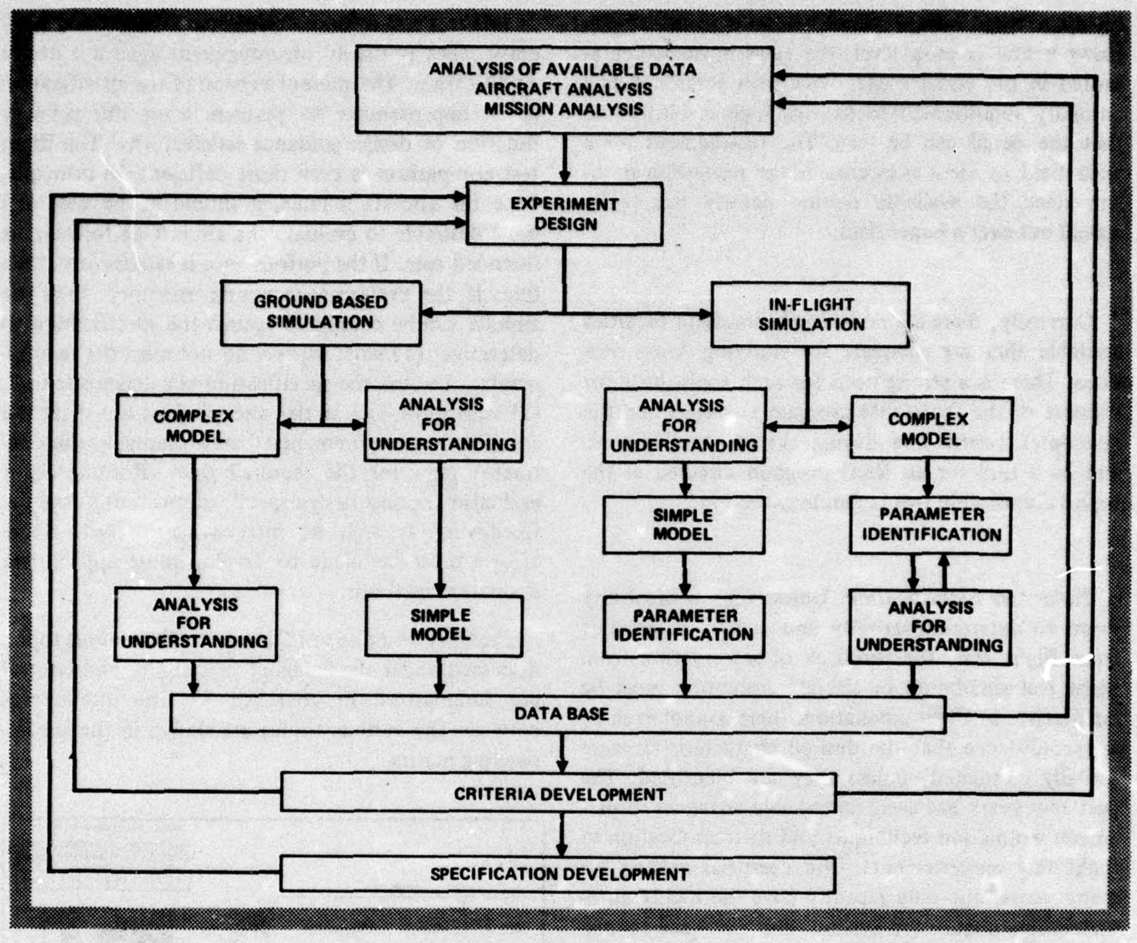


Figure AE–8. Design loop.

low altitudes, which are the conditions of primary importance for V/STOL aircraft and helicopters. Improvements are required in basic turbulence modeling, and in representing additional phenomena such as wind shear and discrete gusts produced by ground obstructions.

Ground Simulators. For conventional aircraft, the capabilities of ground simulators are generally strong. Unfortunately, the Army's use of helicopters as intimate ground contact machines imposes severe requirements, especially on the simulation of the out-the-window scene. In conventional aircraft, speed restricts turn rates so that attention is directed forward most of the time. In such circumstances, the field of view provided by a typical TV display (50 degrees by 35 degrees) may be adequate, though this is more true in the civil environment than the military, where air combat or air-to-ground maneuvers require greater field of view. In helicopters and V/STOL aircraft, the slower speeds allow greater turn rates, and in the limit, hover, the aircraft can go sideways or straight up and down. The field of view required to perform such manuevers, especially in restricted areas such as a clearing in the woods, or nap-of-the-earth flying, is obviously very much greater. Flight at night introduces other considerations; though a helicopter can be hovered in daylight with a restricted field of view, as the details become less distinct, in darkness, for example, the pilot has to search an increasing field of view for the cues he needs to control the aircraft. Hence, simulation of night VMC puts considerable emphasis on providing peripheral cues.

Not only is there a need for a wide field of view, but detail and resolution are also particularly important for Army helicopter tasks such as low-level (NOE) operations. The intimacy between the helicopter and the ground on Army missions necessitates

highly detailed terrain scenes; if one is to investigate flight below treetop level, the trees must be represented in the visual scene. With high detail comes a corollary requirement to provide high resolution so that the detail can be seen. The requirement for a wide field of view exascerbates the resolution problem since the available picture density has to be spread out over a larger field.

Currently, there are no research simulator facilities available that are adequate for studying Army missions. There is a strong need for such tools, both for support of the DARCOM program managers and the helicopter contractors during system development, and as a tool for an R&D program directed at the topics discussed in this technology section.

Parameter Identification. Unless a good capability exists to determine stability and control parameters from flight test, the feedback of information from flight test simulation or aircraft evaluation must be qualitative. In flight simulation, there cannot even be any confidence that the desired characteristics were actually simulated, unless they are identified. The past few years has seen remarkable advances in parameter estimation techniques and their application to flight test measurements. The need has existed for many years, but only recently have the highly automated data acquisition systems and advanced estimation techniques been available that can extract the information efficiently. Most flight test organizations now have experience with one or more parameter identification techniques to determine aircraft stability and control derivatives for conventional aircraft. Some work has been performed on helicopters, but not enough. Helicopters are more difficult to treat than fixed-wing aircraft because the highly vibrating environment produces significant sensor noise, and the non-negligible longitudinal to lateral-directional coupling, and the rotor dynamics, require a very high-order model. If nonsteady (transitioning) flight conditions are included as well, then helicopters share with other VTOL aircraft the extra problem of nonlinear or time-varying equations. A major effort should be made to improve helicopter identification capabilities. This can be accomplished by application of such techniques to current Army helicopters, thereby improving knowledge of our present aircraft and providing a much needed design data base. Parameter identification should also be made an essential ingredient of any flying qualities flight test programs.

Flight Test. System evaluation in flight test presently relies primarily on assessment against a design specification. The present version of the specification needs improvement to perform even this primary function of design guidance satisfactorily. The flight test comparison is even more deficient. In principle, once the aircraft is built, it should be possible and most desirable to evaluate the aircraft performing its intended role. If the performance is satisfactory, then fine. If the performance is unsatisfactory, then the aircraft can be compared against the specification to determine: (1) what aspects do not meet the requirements – i.e., use the specification as a diagnostic tool, (2) who pays, i.e., if the aircraft does not meet the specification requirements then presumably the contractor pays for the required fixes. Routine flight evaluation against design specifications is universal for fixed-wing as well as rotary-wing aircraft. Some efforts must be made to develop more appropriate evaluation methods.

Stability and Control Summary. The various topics discussed under the category of stability and control are summarized in chart AE–V. The interactions between the various topics are shown in the accompanying matrix.

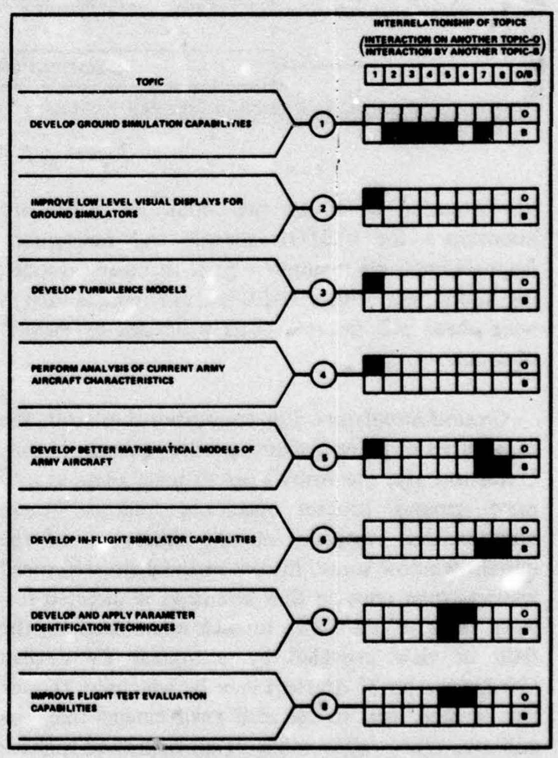


Chart AE–V. Stability and Control Topics Summary

HANDLING QUALITIES

General. Handling qualities describe the flying characteristics which determine the pilot's ability to perform a certain task and the level of workload involved. Since it is an overall assessment, handling qualities must bring together the following specialities involved in aircraft design:

- Aerodynamics
- Dynamics
- Stability and control, controllability, maneuverability
- Displays for guidance and control information
- Mission requirements
- Human factors

This integrated approach cannot be emphasized too much. It is no use performing display studies if the vehicle stability and control characteristics are ignored, nor is it any use studying stability and control characteristics unless the mission requirements and available displays are considered.

Criteria Development. A principal objective of most handling qualities research work is criteria development. Hence, before looking at specific topics needing investigation, it is worthwhile looking at the criteria development process. The block diagram, figure AE–9, shows the general approach. Starting with an analysis of what is presently known about the area of interest, one can pick out the parameters of interest and the appropriate ranges for variation. As was discussed previously under stability and control, the models used may be simple or complex; both have their places in ground simulations and flight simulations. Suitable analysis may allow considerable simplification to be made to the model before performing the experiment. This will allow the results to be more readily associated with the parameters changed. Conversely, if a complex model is used, some form of analysis will be required to make the data useful for understanding the results before, or as part of, trying to develop criteria. Flight simulations must involve parameter identification to aid in setting up configurations and verifying what was actually simulated. Finally, the data must be analyzed, along with what

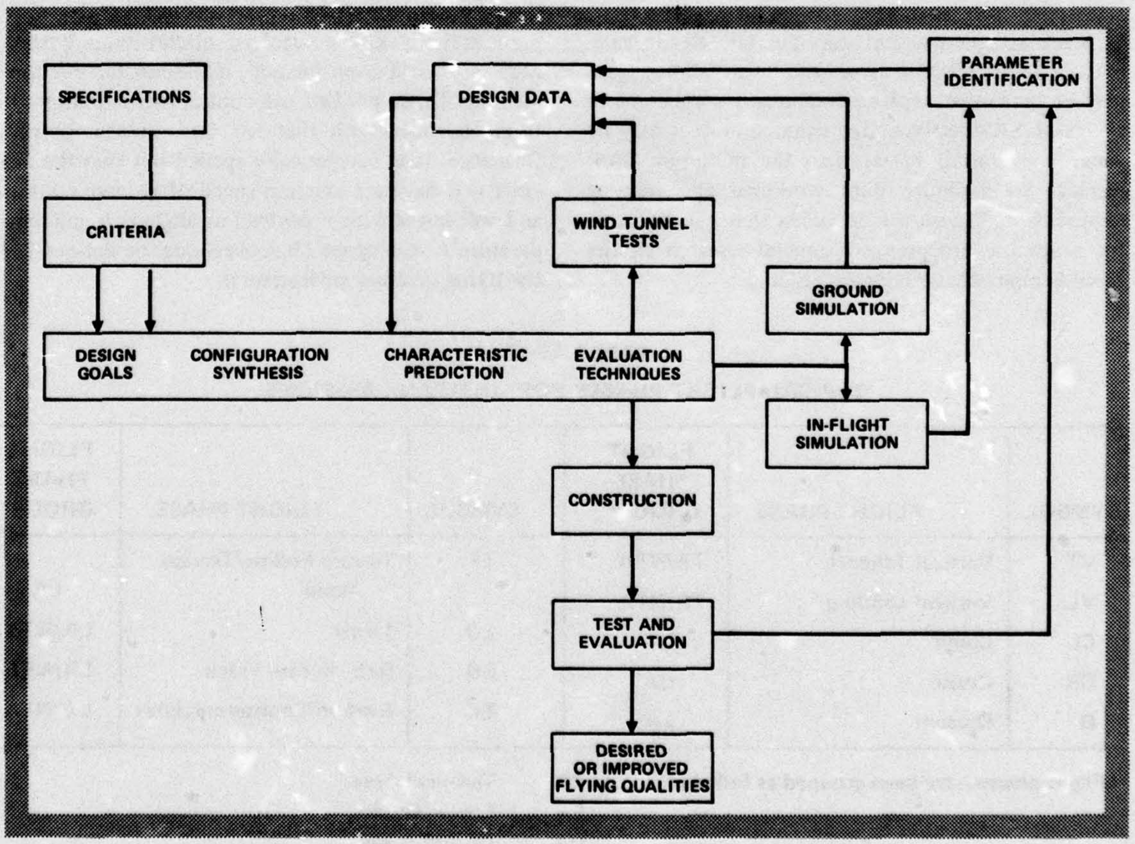


Figure AE–9. Generation of data for handling qualities criteria.

was previously available, to determine if any general statements can be made for design goals or criteria. The extra step of formulating specifications must take a set of criteria and associate them with a concept of reliability so that benchmarks of minimum handling qualities can be entered into contractual documents.

Projects like TAGS, the AH-56 in automatic terrain-following mode, or U.S. Navy helicopters performing sonobuoy dunking on ink-black nights, illustrate that helicopters can be made to do almost anything desired of them; they can be made very easy to fly, or to fly themselves, if we are prepared to pay the price. Unfortunately, we can seldom afford to pay the price for the ultimate, most easily flown system. What we must do is define the minimum systems. We must define the stability and control characteristics (basic and augmented) that, when combined with appropriate displays (raw data, flight director, integrated CRT, head-up, etc.), allow adequate mission performance with tolerable pilot workload and cost-effective training (initial and proficiency).

A few very demanding tasks may take all the capability that the state-of-the-art can muster. Some tasks may be performed with several equally good combinations of SAS/displays. For some aircraft it may be cheaper to install better than the minimum SAS/displays to minimize pilot workload and training requirements. These are decisions that can be made for a specific procurement; general research studies should emphasize defining minimums.

Having spelled out a philosophy for research, the next task is to define the specific topics needing study. This must be approached through an analysis of Army mission requirements and a knowledge of present deficiencies.

Mission Analysis. Aircraft are designed to perform a role, e.g., the AAH has the attack role, UTTAS has the utility transport role. The role involves many types of missions (e.g., the AAH missions in section AH). Each of these missions can be broken down into flight phases, e.g., the AAH anti-tank defense mission may consist of the flight phases listed in table AE–C. The next detail is to associate an environment within which a particular flight phase must be performed. Day, night, visibility, and ceiling are the primary conditions, but wind and turbulence must be added for flying qualities considerations. The general cases for consideration are: weather; clear, rain, snow, icing; and terrain; wooded, field, hilly, flat, snow covered, and sand. It must be noted here that the capabilities desired are usually not well defined; they should be. It is inefficient to perform flying qualities research work to determine the minimum stability and control or display requirements necessary for a given mission, if the mission environment is ill defined. One can contrast the situation for flying qualities with that for performance. In performance, it is categorically spelled out that the aircraft will have a maximum speed of at least x knots and will hover with y payload at altitude h and temperature t. Analogous objectives must be defined for the flying qualities environment.

TABLE AE–C

TYPICAL FLIGHT PHASES FOR ANTITANK MISSIONS

SYMBOL	FLIGHT PHASE	FLIGHT PHASE GROUP*	SYMBOL	FLIGHT PHASE	FLIGHT PHASE GROUP*
VT	Vertical Takeoff	TA/NTA	TF	Terrain Follow/Terrain Avoid	LA
VL	Vertical Landing	TA/NTA	LO	Loiter	LA/NTA
CL	Climb	UA	BO	Bob-Up Fire Track	LA/NTA
CR	Cruise	UA	EC	Evasion/Countermeasures	LA/NTA
D	Descent	LA			

*Flight phases have been grouped as follows:

TA	Terminal Area
LA	Low Altitude
UA	Up and Away
NTA	Non-Terminal Area

Without going into detail as to which class of aircraft needs what minimums, some typical current capabilities can be summarized and compared with goals that may be realistic for the near future (table AE–D). The typical terminal area (i.e., prepared airfields with radio guidance aids and lights) capabilities shown are ICAO Category I. It certainly should be possible (and is desirable) to drive these limits down to lower ceilings and visibilities such as 50/700-ft. These limits are not affected by darkness. Non-terminal area flight phases (such as approach and landing in an unprepared forward area) and low-altitude flight phases (such as NOE or terrain flying) can be typically performed down to 300-ft ceilings and 1/2-mile visibility in daylight. At night, a visible horizon and a light level approaching that of a quarter moon is required. Under tactical situations, it is clearly desirable to drive these minimums down to some lower visual contact minimum such as 50/700 ft. Wind and turbulence can be a severe limitation in any of the flight phase groups and are particularly important in the non-terminal area and low-altitude flight phases since they manifest themselves through turbulence response and out-of-wind hover capability. Wind speed data was prepared by the USAF Environmental Technical Applications Center as background for revisions to specification MIL–F–8785B, "Flying Qualities of Piloted Airplanes." The data was taken from measurements at 266 airfields in the contiguous USA. Local terrain was generally flat, with 1 mile or more unobstructed flow upwind of the anemometer. Table AE–E summarizes this data and shows that a helicopter capable of flying in 34 kt wind would be limited less than 0.5 percent of the time (44 hr/year) in all but a few areas of the mountain and plain states. Even in these high wind areas, 34 kts would be exceeded less than 1 percent of the time (88 hr/year). Although Army

TABLE AE–D
TYPICAL AND DESIRED MISSION ENVIRONMENT CAPABILITIES

FLIGHT PHASE GROUPS		TERMINAL AREA		NON-TERMINAL AREA		LOW-ALTITUDE	
CAPABILITY		TYPICAL	DESIRED	TYPICAL	DESIRED	TYPICAL	DESIRED
DAY	Ceiling - ft	200	50	300	50	300 AGL	50
	Visibility - ft	1000	700	1/2 mile	700	1/2 mile	700
	Wind ∿ kt	20 ± 15	35 ± 20	18 ± 10	35 ± 20	18 ± 20	35 ± 20
NIGHT	Ceiling - ft	200	50	500	50	500 AGL	50
	Visibility - ft	1800	700	1 mile	700	I mile	700
	Light Level - FTC	0	0	Visibie Horizon (VCM)	0	Visible Horizon (VCM)	0
	Wind ∿ kt	20 ±15	35 ± 20	18 ± 10	35 ± 10	18 ± 10	35 ± 20

TABLE AE–E
WIND SPEED DATA

WIND SPEED (kt)	PROBABILITY OF ENCOUNTERING GREATER WIND %	AREA OF HIGH WIND
22	1.0	• Almost all of USA
28	1.0	• Parts of Rocky Mountains and Western Plain states
	0.5	• Most of Rocky Mountains and Plain states
34	1.0	• No areas
	0.5	• Small areas of Rocky Mountains and Plain states

operations will involve flight near obstructions and on mountain sides, where locally greater winds may be encountered, the 35 kt operating speed seems a reasonable near-term goal, and would approximately cut in half the current limits in operations.

In discussing areas to be emphasized, reference can be made to table AE–F, which lists some critical flight phases and the pertinent aircraft classes. DARCOM has defined a major thrust for RDT&E to be night operations, particularly at low level. This thrust is designated LLNO for Low Level Night Operations. Under the umbrella LLNO there are two critical aircraft roles, scout and attack (ASH and AAH). Consider either one, e.g., the AAH. The LLNO mission breakdown in table AE–F can be used as an example. Only the flight phases grouped as LA (Low Altitude) are really pertinent to LLNO research.

The Combat Developments and Experimentation Command, USACDEC, recently defined the potential capabilities of current systems (AH-1G and OH-58) to operate at low altitude at night, with absolute minimum aids. The capability to perform low-level flight (TF) is roughly as shown on figure AE–10. It was found that for flight phase TF, the primary obstacle was visibility. Since CDEC had no means of changing the aircraft stability and control characteristics, the impact of control and maneuverability was indeterminate. Experiments must be performed to determine how the stability and control characteristics influence the task performance and pilot training proficiency requirements. Flying qualities deficiencies were noted in flight phases LO, BO, and EC. These flight phases also need investigation. An overall conclusion was that though attack helicopter teams can operate at nap-of-the-earth altitudes under clear night conditions,

TABLE AE–F
FLIGHT PHASES AIRCRAFT GROUPING

GROUP	FLIGHT PHASES	COMMENT	AIRCRAFT*
LOW ALTITUDE	NOE Contour Low Level	Terrain Follow- Terrain Avoid	S/A S/A/U
	Bob Up	Include Acquisition Fire & Track	S/A
	Evasion		S/A/U/H
	Non-Terminal Approach to Hover Possibly Land	Zero or Minimum Ground Aids	S/A/U/H
I.M.C.	Terminal Area Approach and Land: To Cat II Below Cat II Tailored Profiles	 100 ft/1/4 mi <100 ft and/or 1/4 mi e.g., Steep/Curved	 S/A/U/H S/A/U/H
	Elementary Enroute IMC	Prevent Disorientation	S/A/U/H
SLUNG LOAD	Precision Hover		H/U
	Stability at Speed		H/U
MULTIPLE AIRCRAFT	Formation Flight	May be superimposed on low level flight phases	S/A/U/H
	Air-to-Air Combat		A

*AIRCRAFT	S- SCOUT	OH-6, OH-58, ASH
	A- ATTACH	AH-1G, AAH
	U- UTILITY	UH-1, UTTAS
	H- HEAVY LIFT	CH-47, CH-54, MLH

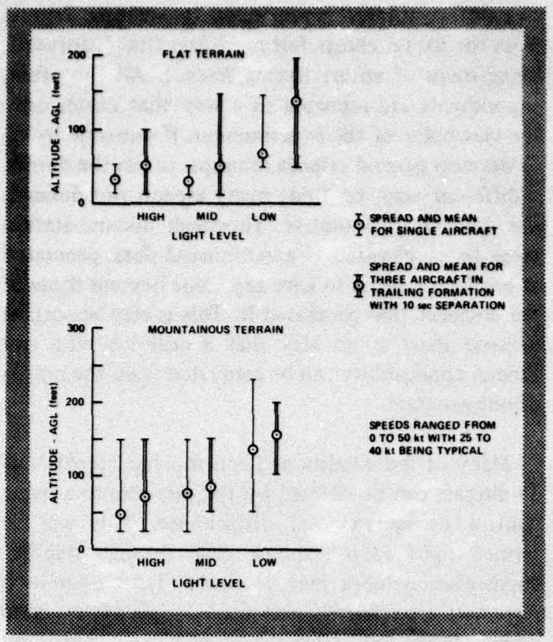


Figure AE–10. Unaided LLNO capabilities.

they cannot routinely perform those interrelated acquisition tasks necessary to engage targets without a night acquisition system. Thus, an investigation of flying qualities in flight phase BO must include avionics equipment and specialists.

Clearly, it is desirable to keep the capability of performing the individual flight phases matched. As mentioned above, the ability to fly TF on a clear night exceeds the ability to acquire the target, BO. However, if aids are provided for target acquisition, capabilities will extend into dark night conditions, and possibly into deteriorating weather. In this case, it will be the TF flight phase that trails. Hence, a long-term program objective must be to improve LLNO mission capability by continued focus on the weakest link in the flight phase chain. Ground simulations, flight simulations, and work with instrumented attack and scout aircraft (e.g., AH-1G and OH-58) are all appropriate for these efforts.

The more general category of IMC is not explicitly a major thrust, but is, nonetheless, an important area needing long term research to generate systematic criteria. There are of course several degrees of IMC and many flight phases which can be conducted under IMC. Perhaps the most elementary IMC capability is to be able to survive unexpected encounter with IMC conditions (such as haze, darkness, dust, night blindness from flares or searchlights, etc.) when performing up and away (UA) flying. This capability is by no means universal in current Army helicopters and considerable effort should be made to ensure that the next generation is better. There is much room for improvement to bring helicopter flying qualities at least up to those for fixed wing. Figure AE–11 compares the percentage of accidents due to disorientation error in Army rotary-wing aircraft with those in Army fixed-wing aircraft. In 1969, this consisted of 65 rotary-wing accidents; 20 were fatal, and the cost to the Army of aircraft alone was $11.7 million. The ability to prevent such accidents needs research, but will be a tradeoff between stability and control and display characteristics and pilot training and proficiency. Figure AE–12 shows how 8000 Army pilots

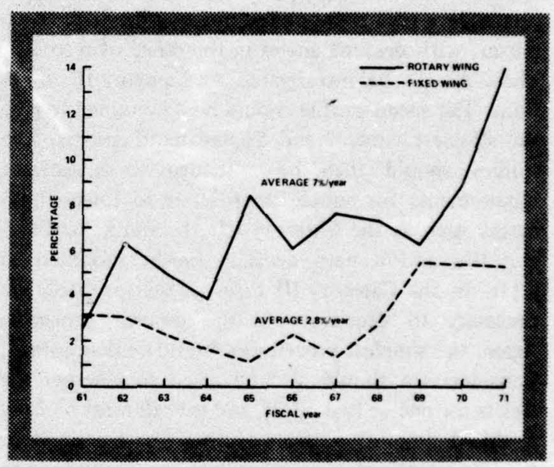


Figure AE–11. Percentage of accidents in which disorientation was a cause factor.

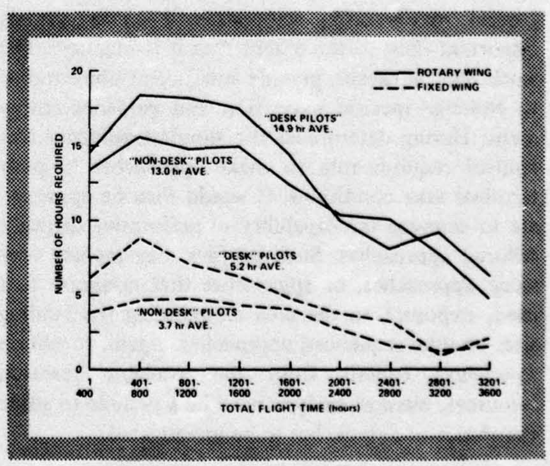


Figure AE–12. Estimated time with instructor in order to become IMC first pilot proficient.

answered the question: How many hours of instrument flight time would you need with an instructor in order for you to fly in IMC safely? Obviously rotary-wing aircraft are more difficult to fly, and a program to improve the flying qualities, at least to fixed-wing standards, should reduce accidents and have the additional benefit of reducing training and proficiency costs. Thus, a broad program of improving rotary-wing flying qualities in IMC should be a major objective. This will start with the elementary ability to avoid disorientation if IMC conditions are suddenly encountered, and move into increasingly severe terminal area conditions as seem appropriate from mission studies.

The type of approaches to be considered should start with simple approach profiles, i.e., straight-in approaches, or skewed approaches as would be appropriate for a collocated glide-slope and localizer transmitter, with descent angles in the range of 6 to 20°. These should be investigated to Category II conditions. The speed profile should be determined to give the simplest control and display requirements. The studies should then be extended to investigate requirements for simple approaches to lower minimums such as the Category IIIa, b, and c, or Category IIIa and b with decision height modified to 50 ft. In the Category III cases, it will probably be necessary to decelerate as the descent proceeds. *Again, the simplest procedures should be determined.* Consideration should also be given to whether the task is for one or two pilots, and if both must be fully qualified. It must be realized that for these studies, the important aspect of displays is what information the pilot needs and how it should be displayed. Whether this information is obtained from the ground, or is from self-contained equipment, is important only to the extent that it is practical. The work does, however, provide an efficient opportunity to exercise specific navigation and guidance equipment. Having determined the simplest guidance and control requirements to make approaches in poor terminal area conditions, it would then be appropriate to examine the capability of performing specially tailored approaches. Such profiles may include very steep approaches, or approaches that minimize fuel used, exposure to the area surrounding the landing site, or time sequenced approaches. Again, to obtain maximum benefit from the available research resources, mission analysis must be a prelude to guide the choice of approaches to be investigated.

Criteria Development. Obtaining the data for flying qualities research is expensive but relatively straightforward. In comparison, generating criteria from the data is cheap, but much less straightforward, being more of an art than a science. All too often, experiments are reported in a way that covers only the viewpoint of the experimenter. If someone trying to develop general criteria attempts to use the data in a different way, he finds many aspects not defined; the data is then useless. Thorough documentation must be emphasized if experimental data, generated at great expense, is to have any value beyond those of the engineer that generated it. This is very important because there is no way that a criterion with any general applicability can be generated from the results of one program.

Many of the stability and control characteristics of an aircraft can be defined by the response to a single control or an external disturbance. This will be termed open loop response even through stability augmentation loops may be closed. These open-loop responses are relatively easy for a designer to evaluate during design, and have therefore been widely used for criteria and specifications. However, there are many flight situations where it is more important to look at the response to a disturbance or control while the pilot is controlling the aircraft with the same or another control. This will be called closed-loop response. Control of speed and descent rate during landing approach is usually a two-control, closed-loop situation, e.g., longitudinal cyclic or pitch control to control attitude, and then mixtures of attitude change and collective inputs to control speed and descent rate. This is a complex situation to analyze because there are many parameters that influence the flying qualities. One tool that may be useful in analyzing and obtaining an understanding of such closed-loop, multiple input/output situations is the use of an analytical pilot model. However, what is being advocated is the application of available pilot models, not the development of new, more complicated models. Available models are already more complex than required and have to be simplified for useful application. Work in the near future should be toward more systematic application of pilot models where they appear to be useful.

Specifications. Since a primary use of stability and control criteria is to generate and improve flying qualities specifications, a few words are warranted on the current specification status. The helicopter flying qualities specification MIL–H–8501A is a 1962 revision of a 1952 document. Several efforts have been made to revise this document, so far without

avail. The reason is not a lack of ideas for improvements, but a lack of data with which to substantiate these ideas. In 1970 a new specification, MIL–F–83300, was adopted for piloted V/STOL aircraft. The U.S. Air Force made MIL–F–83300 applicable to helicopters as well as other types of V/STOL aircraft, but the U.S. Army and the U.S. Navy excluded helicopters and retained MIL–H–8501A. A review of the relative advantages, disadvantages, and shortcomings of MIL–F–8785B, MIL–F–83300, MIL–H–8501A, and proposed revisions to MIL–H–8501A, requires an extent and detailed depth that is quite out of place here. The important point to be made is that data must be obtained, starting in the areas discussed in this chapter; then work on criteria development must be pushed so that better, more complete requirements can be developed and substantiated.

Handling Qualities Summary. The approach and objectives of the research topics categorized as handling qualities are summarized as follows:

- Develop Army aircraft capabilities and requirements through mission analysis
- Develop data base through ground and in-flight simulation
- Develop design criteria
- Update handling qualities specifications

SUMMARY OF FLIGHT CONTROL OBJECTIVES

The goals and objectives propounded for flight control that are discussed at length in this section are summarized in chart AE–IV. This chart shows two types of objectives:

- Technological objectives
- Achievement goals to be accomplished through the technological objectives

Progress in accomplishing the achievement goals will be made only by a broad and balanced technology program comprising analysis, experimentation, and development. Experimentation is more costly than analysis, and flight test or in-flight simulation is more costly than ground based simulation; system development is generally the most expensive of all. These constraints have been kept in mind in generating the R&D programs discussed later in the Program Annex to this section.

ACOUSTICS

AERODYNAMIC NOISE CONTROL

General. Acoustic waves originating on the advancing blade of typical rotary-wing configurations produce a distinguishing acoustic signature described as blade slap. In addition, strong near-field interactions can occur between both mixing pockets and tip vortices within the rotor wake and the rotor blades that cause them, thus producing a combination of impulsive harmonic noise. Superimposed on these events is a significant measure of broadband noise due in part to inflow turbulence and localized blade stall. Mechanical sources of disturbing noise, which stem from the engine and transmission, also add to the acoustic problem, but will be discussed in a separate section of this plan. Regardless of the source of noise, be it aerodynamic or mechanical, the advent of larger rotorcraft flying at even higher subsonic forward speeds will be plagued with further increases in external and internal noise levels to the extent that detectability, annoyance, and crew health could seriously limit mission effectiveness during tactical and training operations.

Noise-Performance System Studies. It is generally known that decreasing rotor tip speed is often an effective way of decreasing the external noise levels of rotary-wing aircraft. Unfortunately, decreasing noise levels through tip speed reductions is expensive in terms of vehicle performance. Whether such tip speed reductions or other methods of reducing noise are important enough to warrant performance sacrifices for a particular helicopter configuration are questions best answered through systematic parametric studies. Such studies should focus on all aspects of noise control; controlling noise at the source, propagation, and detection. Competing methods of controlling noise at the source should be examined to determine the effectiveness and cost in tactical situations. Typical rotorcraft maneuvers, in relation to terrain irregularities, should be examined to determine the extent of spectral reordering and propagation directivity. Finally, this effort should highlight those areas of acoustic research that are most cost-effective to the Army's mission requirements.

Source Control. While there may be some controversy over the precise contributions of various flow disturbances, as well as the subjective perception of their collective noise signature, specific discernible features of the rotor environment can be identified as candidate sources of aerodynamic noise production.

Rotor-wake interaction and high-speed, unsteady flow are thought to be the two primary causes of rotor impulsive noise – or blade slap. Inflow turbulence (atmospheric or self-induced) and localized blade stall are primary candidates for the source of broadband noise. A systematic and detailed experimental program is needed to collect and correlate dynamic blade loadings and rotor wake properties with acoustic measurements. Because of the difficulty of establishing a unique relationship between the noise source and the far-field noise, this effort will no doubt require an extensive facility qualification study to assess the reliability of the data gathering procedures under all flight conditions. The development of new and unique methods of collecting and analyzing acoustic data are anticipated.

As a particular noise source becomes more completely quantified, it will be possible in many cases to refine mathematical models of the event. Then, by judiciously altering parameters of the model, it will be possible to predict changes in the radiated sound. For example, having traced a sizable noise contribution to unsteady compressible effects arising from interactions of the rotor blade and the tip vortex, it seems natural to question the potential of a reorientation of the individual blades within the rotor system. Suggested modifications include blade sets with different diameters, uneven angles between blades (either permanently fixed or variable in flight), and unequal elevations of the tip path planes of two sets of blades. Other than merely trying to avoid strong vortex interactions, it is conceivable that the strength and trajectory of each tip vortex can be favorably altered through new blade tip geometries or airflow injection. Rational and systematic assessments of these approaches, and the performance penalties they might entail, require the development of advanced aerodynamic and acoustic models. These theoretical and experimental techniques are interdependent with an understanding of basic aerodynamic phenomena and, as such, rely heavily upon those disciplines.

Trajectory Management. An important means for minimizing detection distances and annoyance of rotary-wing aircraft is through flight path management. Tailoring flight profiles to reduce noise has been shown to reduce dramatically the blade slap problem on certain classes of helicopters. Unfortunately, adapting operational procedures is difficult to implement effectively because these procedures must be tailored to reflect mission requirements, rotorcraft performance and stability characteristics, area navigation constraints, and safety and survivability factors. The analyst has also had to contend with an insufficient understanding of noise-producing mechanisms, a lack of reliable acoustic data from field tests, and an assortment of inadequate prediction techniques. An aggressive and continuing effort is clearly required to remove these deficiencies and thereby establish needed trajectory guidelines for reducing acoustic detectability and exposure time.

Subjective Acoustic Criteria. The helicopter is unique in many ways – especially in its ability to generate intense low-frequency noise, which is commonly called blade slap. Blade slap radiates great distances, often diffracting from line of sight, and can be one of the first measures of detection distance. Unfortunately, little is known about how easily this low-frequency noise can be detected. Basic psychoacoustical research is needed to determine those parameters of a blade slap signal that are important for detection. Complementary studies should be commenced to focus on quantifying the annoyance of helicopter acoustical signatures.

INTERNAL NOISE

High noise levels in the cockpit of modern helicopters is common. Large power generating and transmission devices are, because of unavoidable design factors, located in close proximity to crew stations and usually dominate internal noise levels. Although it is possible to place acoustic blankets over these noise sources, current noise reduction materials decrease noise by the mass law and, as such, are quite heavy. Current Army practice is to do what can be done to quiet the cockpit at reasonable cost and then design helmets to protect crew members from excessive noise. Although not the most ideal solution to the problem, it is one that minimizes performance sacrifices in helicopter design. Additional effort should be expended to lower internal noise levels through better engine and transmission design and to develop isolation materials that reduce noise and are relatively light weight. These topics are addressed in a different section of this Plan.

ACOUSTIC TOPICS SUMMARY

The various research topics discussed under acoustics can be categorized as listed in chart AE–VI, with the interrelationship between the topics shown by the accompanying matrix. Should each of the areas be adopted as an element of a unified research program, the quantified achievement goals indicated in chart AE–I could be attained.

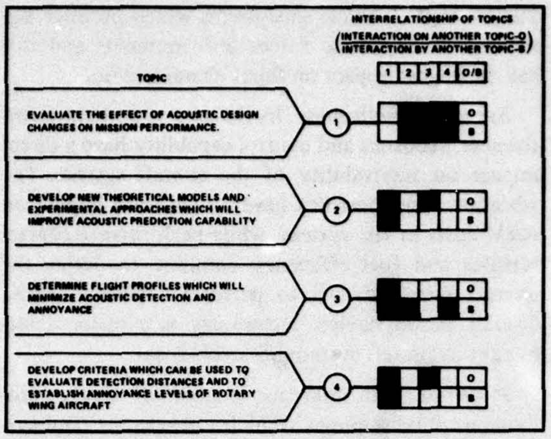


Chart AE–VI. Acoustics Topics Summary

EXPERIMENTAL TECHNIQUES

The development of theoretical prediction methods depends strongly on reliable ground test data for verification and inspiration. Facilities and techniques typically used for such purposes include wind tunnels, powered tracks, towed trailers, and tether rigs. Unfortunately, there has been a lack of correlation in V/STOL aircraft data from these sources.

Present wind-tunnel configurations and data gathering procedures are not entirely satisfactory for low-speed V/STOL testing. For example, theories currently being used to correct wind-tunnel measurements due to wall effects are often no more trustworthy than are the theories the experiments are intended to verify. In addition, there can be considerable uncertainty as to the validity of model rotor scaling.

Determination of ground effects on V/STOL performance at low speeds is also an important experimental task; however, even for stationary models, these effects cannot be satisfactorily assessed in many conventional wind tunnels because of the interaction between the model wake and the boundary layer on the tunnel floor. This interaction can be minimized by using a moving-belt ground plane; however, the effectiveness of this procedure is reduced in tests that require the model to change attitude and position within the tunnel. This condition requires further investigation if simple quasisteady analyses based on stationary model test results are found to be unacceptable for describing actual ground-affected transient maneuvers. It is conceivable that practical constraints might limit experiments of this type to rotorcraft mounted on ground-borne test vehicles.

Continuing progress in rotor-acoustic research depends on the ability to separate more completely the rotor noise spectrum from background and reflected noise. This will necessitate modifications to existing wind-tunnel sections and the use of new data gathering procedures. Improved methods are also needed for recording and analyzing the spectral content of a wide range of noise sources.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the aerodynamics discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the aerodynamics discipline can be established from the near-term quantified achievement goals listed in chart AE–1. The near term aerodynamics objectives are of two types: first, those which will result in direct technology improvements and second, those which improve prediction capability and produce indirect technology and cost improvements. The aerodynamics objectives are as follows:

- Achieve ±10% accuracy in the prediction of overall db level of aerodynamically generated noise and reduce this noise by 15%.
- Achieve 20% improvement in predictability of stability and control characteristics.
- Determine handling qualities criteria for LLNO/NOE operation and increase agility by 10%.
- Reduce accidents due to pilot workload by 10%.
- Reduce pilot training requirements by 10%.
- Improve aeromechanical stability prediction techniques to ±10% of measured values.

- Reduce cockpit vibration levels by 50% with minimum weight penalty.
- Achieve 20% reduction in vibratory blade stresses and control system loads through stall modification.
- Achieve ±10% prediction error in key performance parameters.
- Achieve 10% improvement in performance through use of advanced airfoil sections and reduced airframe and hub drag.

PROGRAM PRIORITIES

General. Table AE–G presents, in a prioritized listing, the aerodynamics technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The aerodynamics technology subdisciplines are represented by the major topical areas as presented in table AE–H.

Vehicle Subsystems. Vehicle subsystems, as related to aerodynamics technology, are categorized as follows:

- Lift/propulsion elements – rotors, propellers, wings.
- Auxiliary control elements – tail rotors, control surfaces.
- Parasitic elements – fuselage, landing gear, external equipment.

These are the vehicle subsystems which produce significant aerodynamic forces and moments and this has the largest impact on flight characteristics.

System Effectiveness. In the area of systems effectiveness, acoustics and control capability have a direct impact on survivability of the aircraft system. The vibration characteristics have a significant impact on R&M costs of the system, while performance characteristics and fuel efficiency combine to define the aircraft size and cost to perform a given mission. Overall, aerodynamics technology is a major determinant in aircraft system life cycle costs.

Priorities. With reference to table AE–G, the aerodynamic subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

Assessment of the priority listing in table AE–G and the near-term objectives indicates that the first priority major thrust in aerodynamics technology is consistent with the first and second objectives listed above and is aimed at improving the survivability of aircraft systems to make them more effective. If an aircraft is not survivable, all other aspects of life cycle cost are relatively insignificant. In addition to surviving in a combat environment, an aircraft system must be effective, and flight controls, dynamics and performance characteristics are all tailored to produce a cost effective system. Each one of these elements is necessary to developing systems with acceptable life cycle costs, and the Laboratory thrusts are developed to provide aerodynamics technology which will result in the highest payoff in system cost in the shortest elapsed time.

TABLE AE–G

PRIORITIZED AERODYNAMICS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Acoustics	I	• Main rotor	I	• Survivability	I
• Flight control	II	• Tail rotor	II	• R&M cost	II
• Dynamics	III	• Flight controls	III	• System cost	III
• Fluid mechanics	IV	• Fuselage	IV	• System volume	IV
				• Fuel efficiency	V

TABLE AE–H
AERODYNAMICS SUBDISCIPLINE MAJOR TOPICAL AREAS

SUBDISCIPLINE	MAJOR TOPICAL AREA
ACOUSTICS	• Pertains to the prediction and alleviation of external and internal noise levels produced by: Impulsive compression waves originating on rotor blades and propellers. Strong near field interactions between both mixing pockets and tip vortices. Inflow turbulence (broad band).
FLIGHT CONTROL	• Stability and control refers to the prediction and improvement of the aerodynamic forces and moments which affect aircraft rigid body steady state trim conditions and dynamic behavior. Handling qualities is a term which encompasses the interaction between aircraft stability and control characteristics, displays, task performance and pilot workload. • Control elements cover control system, components, and sensors and include development of the finctional capabilities and demonstration of certain systems. • Control theory is defined to cover the general topic of theoretical design techniques for achieving predefined control characteristics. The application of optimal control is an example of a potentially powerful and useful tool which will require continued development, but requires a defined goal which is lacking at this time.
DYNAMICS	• Aeromechanical instability pertains to a class of dynamic phenomena in which system stability depends on the nature of the mechanical elements alone, and combinations of mechanical elements and aerodynamic forces. Examples of the former include "ground" resonance, shaft whirl and unsymmetrical rotor whirl while the latter include classical blade flutter, stall flutter, and "air resonance". • Vibratory loads are concerned with aerodynamic forces and moments which excite structural response and those which are proportional to elastic deformation. • Aircraft vibration includes the prediction of elastic and rigid body response (amplitude and frequency) due to aerodynamic and inertial excitations and includes vibration isolation by means of parasitic devices or stiffness/mass control.
FLUID MECHANICS	• This subdiscipline relates to all of the above subdisciplines plus the following: Performance pertains to the prediction and improvement of steady state flight capabilities including hover, vertical and maximum rate of climb, cruise and maximum level flight speed, sideward and rearward flight speeds, autorotation and maneuvering flight load factors. Aerodynamic experimental techniques addresses the general areas of wind tunnel testing, configurations, and accuracy. The development of reliable prediction techniques for aerodynamic forces and moment depends strongly on the availability of reliable ground test data produced by experimental techniques.

LABORATORY PROJECTS IN AERODYNAMICS

INTRODUCTION

Aerodynamics technological development effort is directed towards research and exploratory development to increase knowledge in the physical and behavioral sciences. This effort is conducted primarily by AMRDL Directorates collocated with NASA Ames and Langley for the 6.1, 6.2, and some 6.3 efforts and with the addition of the Eustis Directorate for 6.2 and 6.3 efforts.

Programs at the Ames Directorate are primarily in areas of rotor aerodynamics, rotor dynamics, stability and control, handling qualities and aerodynamically generated noise, and are influenced by the availability of such facilities as the Army 7X10 Foot Low-Speed Wind Tunnel, NASA's 40X80 Foot Full-Scale Wind Tunnel, and NASA's Ground-Based Simulators.

Programs at the Langley Directorate are primarily in the area of improved analytical tools and prediction techniques for rotors, which include measurement techniques, unsteady aerodynamic phenomena, airfoil development, performance, rotor wake, and tip vortex characteristics. This work is influenced by the availability of such facilities as the V/STOL wind tunnel, the Transonic Dynamics Tunnel, and the rotor whirl tower.

Programs at the Eustis Directorate are in the 6.2 and 6.3 categories and cover such areas as helicopter drag predictions, comprehensive aeromechanics math modeling, and development of advanced rotor and flight control concepts.

DESCRIPTION OF PROJECTS

Research in Aerodynamics. Project 1F161102AH45-TA I consists of basic and applied research conducted in participation with NASA to develop the aeronautical technologies of rotary-wing aircraft. These in-house, theoretical and experimental investigations are directed toward elimination of the technological voids that are assessed to be potential limiting factors in the development of future superior, reliable, and economical Army airmobile systems. The work performed under this project at the Ames and Langley Directorates is a coordinated and complementary aerodynamic research effort. The division of this aeronautical research between these two Directorates is primarily determined by the particular facilities and/or expertise uniquely available to each. This enables AMRDL to bring all the capability in aeronautical research that is available to these two Directorates to bear on the problems relevant to Army airmobile systems in the most effective manner.

Aerodynamics Technology. Project 1F262209AH76-TA I is an exploratory development effort to develop and demonstrate the technologies, techniques, and design criteria necessary to provide adequate performance, acoustic signatures, stability, control and handling qualities for the Army's rotary wing missions, and to improve the capability to analyze and predict these characteristics in existing and future aircraft. This technology will increase the aircraft's availability and survivability as well as provide for improved operational effectiveness and mission capability of Army aviation systems. Research from this project will provide part of the analytical and design techniques necessary for establishing realistic design goals, and making valid prediction and analyses of the performance, handling qualities, stability and control, and acoustic signature, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by Eustis, Langley, and Ames Directorates in participation with NASA. The programs involve analytical and experimental investigations utilizing ground based and in-flight simulators, wind tunnel and flight test investigations.

Advanced Helicopter Development. The objective of Project 1F263211D157 is an advanced development effort for the development, verification, and demonstration of technology for those areas currently restricting the success of current Army airmobile systems or areas that have prevented the achievement of future Army aviation objectives. The project is formulated on the basis that advances in state-of-the-art technology can only be made if technology is validated in component or system demonstration in actual or simulated flight conditions.

This project consists of the following four major tasks areas:

- *Task II – Advanced Rotor Development.* Under this task advanced rotor systems are developed by the Eustis, Langley and Ames Directorate, with selected concepts jointly funded by NASA. The program is oriented toward a variety of systems, a substantial number of which will be developed through the use of the Rotor Systems Research Aircraft (see Section AT – Advanced Technology Demonstration).
- *Task 12 – Rotor and Control Improvements.* The objective of the flight control portion of this project is the development, verification, and application of improved flight control elements to provide improved mission capability and survivability, and/or improve reliability, maintainability and cost effectiveness. Scope includes the integration of control system elements and displays into the aircraft system performing the appropriate tasks. Past efforts have centered around demonstration of fluidic SAS components, fan-in-fin yaw control, and TAGS/pilot cueing. These efforts are nearing completion. A major thrust for the future will be to apply the results of 6.2 exploratory development to include the capabilities of performing low-altitude operations in poor visibility conditions (LLNO) with minimum dependence on expensive and complex equipment. To prepare for this, an in-flight simulator being developed

by NASA has been converted into a joint program with the Ames Directorate. This will provide the capability to investigate stability and control and display tradeoffs while performing LLNO flight tasks. Development of control system hardware is a Eustis Directorate function.

- *Task 17 – Advancing Blade Concept.* The ABC program has essentially been completed with the successful demonstration of the concept in the helicopter mode. Documentation of the results from the ABC test program is currently underway. See Section AT for additional material on the ABC program.

- *Task 18 – Second Generation Comprehensive Helicopter Analysis System.* An interdisciplinary aeromechanics analysis system for rotorcraft is being developed to provide an integrated analysis capability for prediction of rotorcraft loads, performance, stability and control, dynamics and acoustics. This analysis system will serve as a focal point for aeromechanics methods development and provide preliminary design, detail design, and development support for systems under development through the 1990 time frame. A Government/Industry Working Group has formulated requirements for the system and will assist in monitoring the development.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the aerodynamics R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 aerodynamics R&D efforts are shown in table AE–I. Included in the table is the ratio of the aerodynamics efforts to the total 6.1, 6.2, and 6.3 AMRDL R&D efforts.

TABLE AE–I
AERODYNAMIC TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.1	1F161102AH45-TA I	2227	50%
6.2*	1F262209AH76-TA I	1875	12%
6.3	1F263211D157	4303	30%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

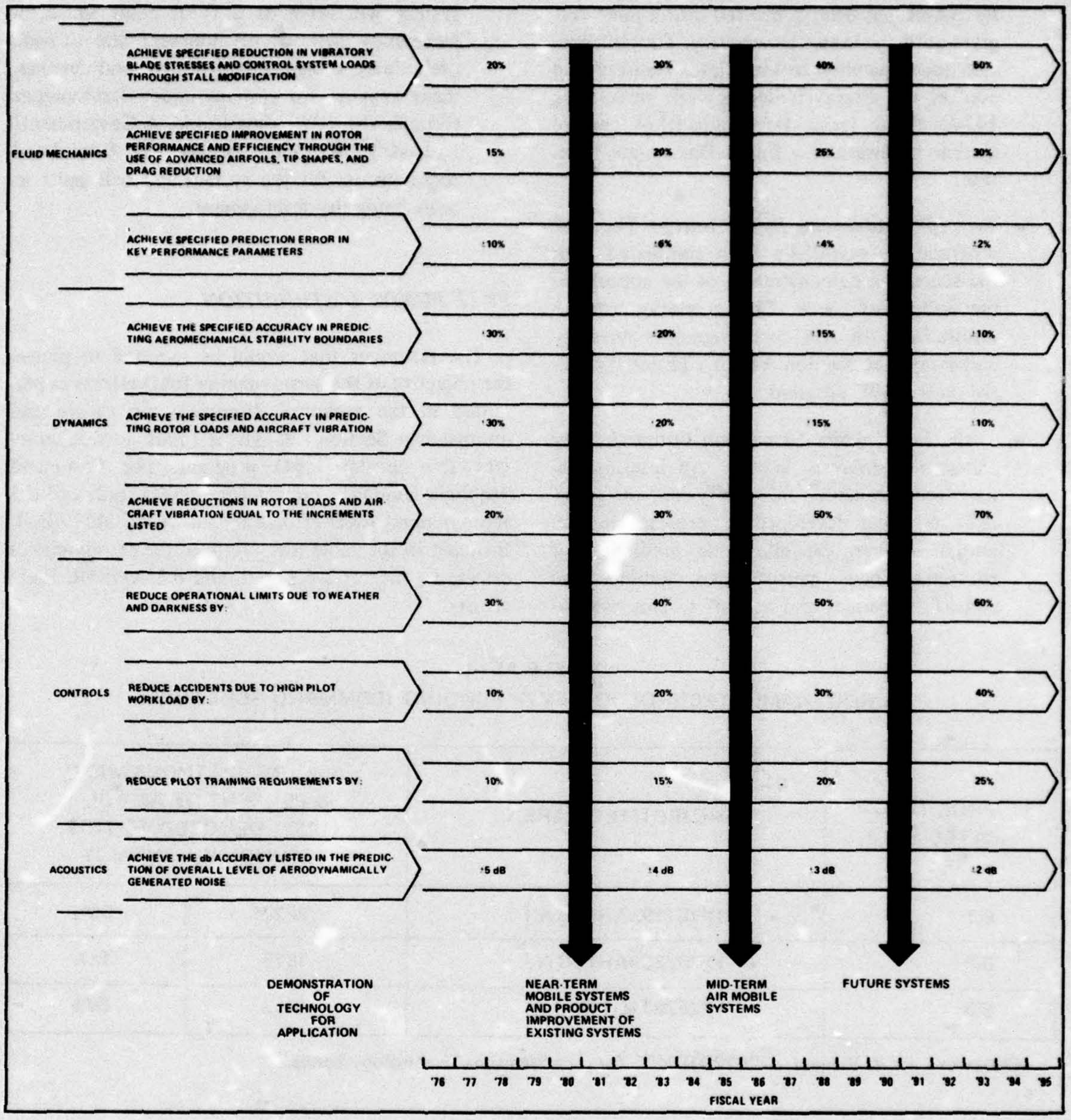


Chart AE–I. Aerodynamics Achievement Goals

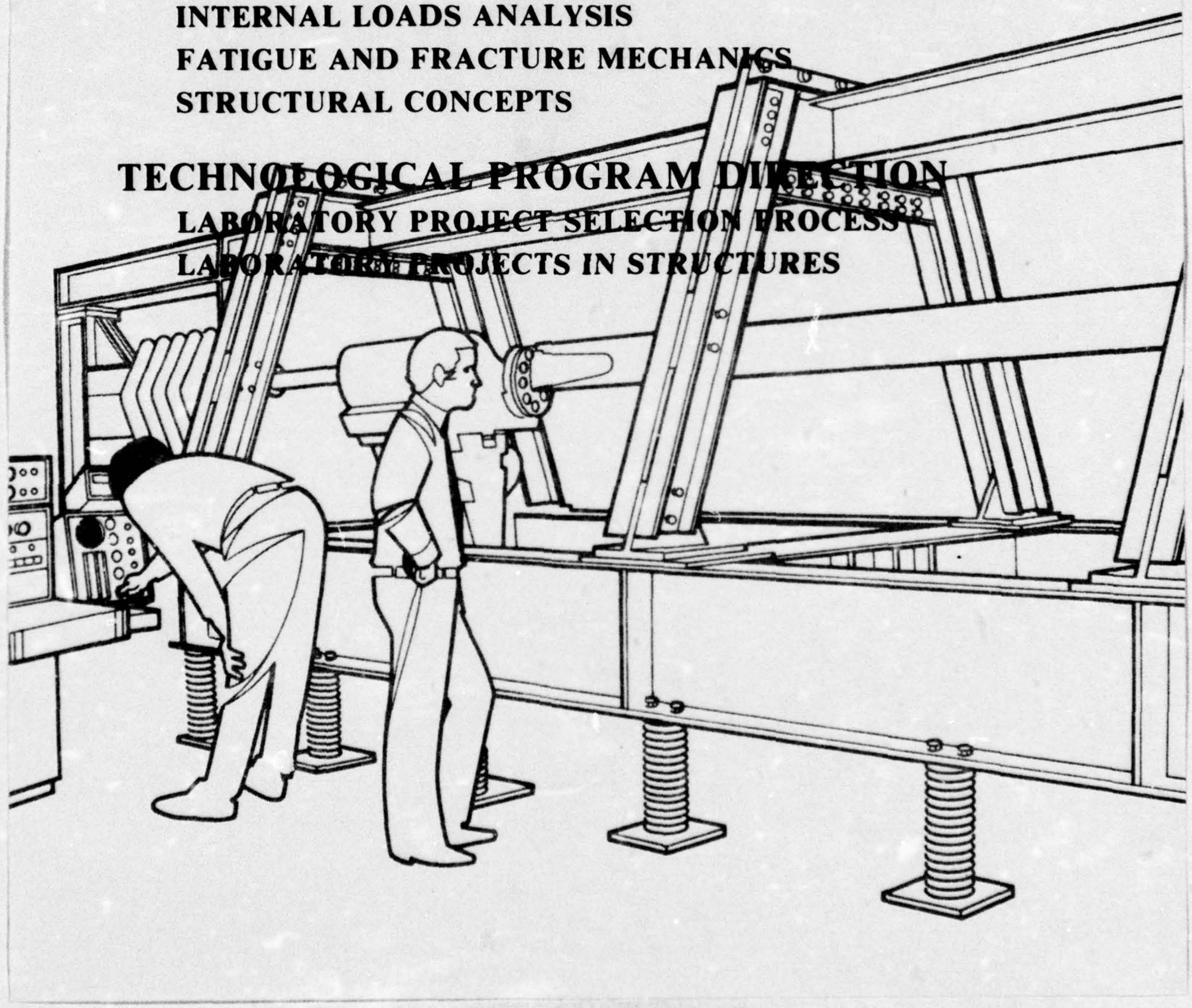
INTRODUCTION

TECHNOLOGICAL DISCUSSION

- CRITERIA
- WEIGHT PREDICTION
- MATERIAL ENGINEERING
- EXTERNAL LOADS ANALYSIS
- INTERNAL LOADS ANALYSIS
- FATIGUE AND FRACTURE MECHANICS
- STRUCTURAL CONCEPTS

TECHNOLOGICAL PROGRAM DIRECTION

- LABORATORY PROJECT SELECTION PROCESS
- LABORATORY PROJECTS IN STRUCTURES



INTRODUCTION

The structures technology area offers one of the greatest payoffs from a well-planned and well-funded program: reduced structural weight, reduced maintenance, increased reliability, and improved survivability benefits can be applied to the next generation of Army aircraft. Potential future Army aircraft systems include a variety of aircraft varying in size from small scout vehicles to very heavy lift aircraft. In each case, the supporting research and technology in the structures area must be guided by past operational experience and present technological limitations. The extensive use of helicopters in Southeast Asia has drawn into focus structural deficiencies and lack of adequate structural design criteria for Army aircraft. The environment, operational procedures, load spectra, and mission profiles represent a use virtually foreign to the original design criteria or military specifications for their structural design. This lack has been reflected in tail rotor failures, tail boom failures, flight control component failures, limited-life dynamic components, fatigue cracking of the basic airframe, and other structural failures. The helicopter's record of fatigue failure accidents remains very poor when judged by fixed-wing standards. The mission requirements of future aircraft systems require an expanded operating envelope involving speed and maneuverability. These requirements must be met with an aircraft that is highly survivable, rugged, and reliable, and that requires a minimum of maintenance and inspection, at a reasonable cost. Improving structural efficiency through research will minimize unproductive weight in future aircraft, permit these requirements to be met, and reduce operating costs.

This research and development activity is, to a great extent, applicable to all of the Army's planned airmobile missions. In some instances specific R&D activities are required to resolve key problems peculiar to certain missions. Examples of the latter are:

- The second generation aerial weapons system require an aircraft with exceptional survivability characteristics. Research and development activities include the development of armor materials that can defeat projectiles for minimum weight and perform effectively as primary structure. Analytical techniques, materials, and structural concepts are developed to safely tolerate gross combat damage from high-energy projectiles in unarmored structure.
- The mobility and intelligence missions will require advanced rotor systems, which might include tilt rotors or tilt wings. Structural criteria, weight methods, and loads prediction methods will be developed to ensure that these concepts become structurally viable systems.
- The mobility mission for oversize payloads requires a lifting capability in the range of 22-1/2 to 50 tons. Current estimates indicate that conventional propulsion systems might not be adequate for a conventional type VTOL vehicle. Materials and structural concepts can be developed to provide off-the-shelf technology for reaction-drive concepts.

The requirement for expanded flight envelopes, the extremely difficult loads environment, and the complexity of VTOL systems dictate the need for an extensive structures program. The development of better analytical tools must be coupled with a better understanding of loads, stresses, and design criteria for the total spectrum of vehicle concepts being considered. Experimental flight test programs involving aerodynamics, dynamic and structural instrumentation must be conducted to guide and substantiate the analytical techniques. These analytical tools must be verified through design, fabrication, and test of actual structural components that also demonstrate, in flight programs, the confidence required to put the structures technology on-the-shelf for developmental aircraft.

To achieve the required technological goals to support the Army's projected aircraft system needs in the structures area, a balanced research and development program must be carried out in each of the subdisciplines, which include structural criteria, weight prediction methods, materials engineering, external loads, internal loads, fatigue and fracture mechanics methods, and structural concepts. Each subdiscipline is interdependent on the others. As efforts progress from basic research through applied research and development, this interdependency of the subdisciplines makes quantitative improvement goals more sensitive to the pacing key parameter. There is also an interdiscipline dependency that will affect attaining future quantitative goals in the subdiscipline areas (i.e., improvements in predicting external loads are dependent on improved understanding of the aerodynamics and dynamics).

The rational meshing of the subdisciplines to develop improved structural concepts is shown on chart ST-I (located at the end of this section). Projected quantitative improvements are shown as reductions in weight as a convenient measure. In actuality, much of the potential weight savings may be traded off for improvements in survivability, safety, reliability, maintenance, and cost. A quantitative assessment of advances in the state-of-the-art in each subdiscipline as they might apply over the 20-year period with application on near-term, mid-term, and future airmobile systems is also shown in chart ST–I.

TECHNOLOGICAL DISCUSSION

CRITERIA

Structural criteria are developed for each aircraft system from the expected use of the vehicle and define the critical design requirement to be met in the design, satisfied in the fabrication, and substantiated during testing. The criteria, when met and substantiated, ensure the structural integrity of the operational fleet of aircraft. At the present time, structural criteria for Army aircraft are based on military specifications, specific mission requirements of the aircraft to be developed, and the Helicopter Engineering AMCP 706–201–203.

The recent advances in rotary wing aircraft performance and the greatly expanded combat role have made the existing military specifications for helicopters inadequate. This inadequacy in structural criteria, with the changing mission, has been shown in the fatigue-limited life of many components, the amount of maintenance required, and the less than desired survivability. In addition, design criteria do not exist for advanced systems such as compound helicopters and tilt rotors that have capability beyond present experience.

The basic objective of research and development in this area is to establish requirements that will ensure an acceptable design life for the intended mission. The criteria must be complete to ensure that all critical parameters are considered during design to avoid costly design changes during aircraft development and test and retrofit after deployment. Most importantly, the criteria must be adequate to prevent catastrophic failures.

One measure of adequate structural criteria is the life of critical components. Ideally, the life of all components would be the same as the design life for the aircraft. At present, many components have limited lives requiring expensive removal and replacement. It is recognized, however, that in some cases life cycle cost analysis might justify selection of a component life less than the system life. For those parts that have a limited life, it is desirable to remove them only when there is an indication of obvious degradation, rather than at some established number of hours, based on the most severe case in the inventory. The "on-condition" removal allows the aircraft with more moderate use to have extended life on the components. Figure ST–1 shows objectives for improvements in these two parameters of design life and on conditional replacement of limited-life parts.

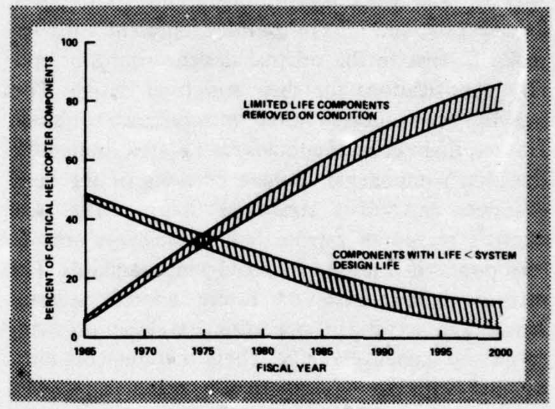


Figure ST–1. Structural criteria improvement goals.

Chart ST–II shows the interrelated efforts that can be pursued to improve the state-of-the-art of criteria development and resolve mission-peculiar criteria problems. Specifically, effort is needed to relate existing criteria to mission requirements, aircraft capability, and actual aircraft use to identify areas of inadequacy. Criteria need to be expanded to cover the increased capability of advanced aircraft concepts being considered for mobility and intelligence missions (i.e., compound helicopters, tilt rotor, etc.). Structural criteria must further be improved to make certain that the new aircraft concepts are designed for increased safety and survivability, reliability, maintainability, and adequate fatigue lives, and that the testing requirements will ensure that the design criteria have been met prior to fielding a new aircraft system.

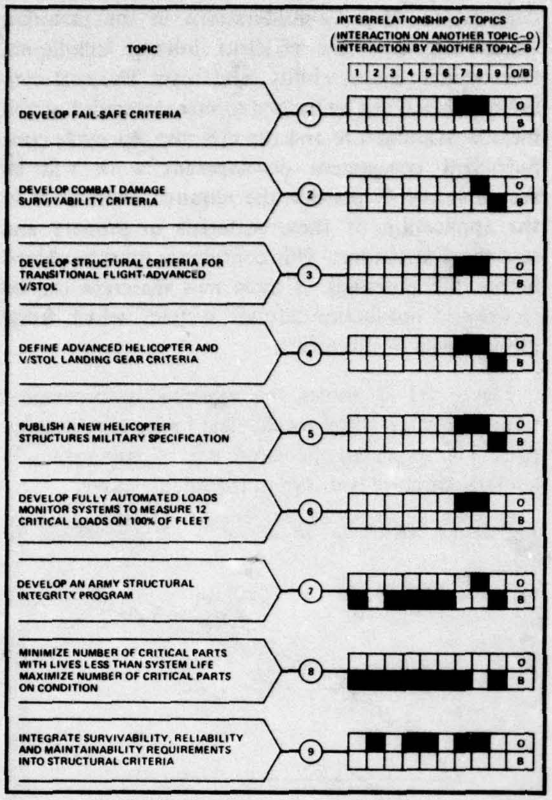


Chart ST–II. Structural Criteria Topics Summary

The immediate goal is to establish criteria to overcome service-revealed deficiencies. Specific programs have been initiated or are planned for comparison of existing helicopter use with the original design criteria to establish a basis for specific improvements. Fail-safe criteria are being developed for improved safety and survivability. Fatigue monitoring systems are being investigated for more accurate determination of mission profiles and fatigue damage across the fleet of Army aircraft. Testing methods and criteria are also being developed to evaluate more accurately the ability of new components and aircraft to live in the Army environment. The ultimate objective is a helicopter structural integrity program which will assure adequate structural performance throughout the life of the aircraft.

WEIGHT PREDICTION

The ability to predict the weight of a new aircraft system in its early stages at the component level and on through the development of the total vehicle can influence the performance of the eventual flying vehicle as much as the aerodynamic calculations. Empirical trend curves have been developed that predict the weight of new systems based on the actual weight of equivalent aircraft systems. Mathematical formulas have been developed that account for several parametric variables. Where few if any equivalent structures or components exist, weight prediction methods are poor and few analytical tools have been developed to improve their accuracy.

The basic objective in this area is to improve the accuracy of weight predictions so that the performance of the first flight vehicle agrees with the predictions. This can be accomplished through developing improved methodology in conjunction with preliminary design efforts that combines trend information with structural sizing based on quick loads and stress analysis. In the cases of a one-of-a-kind system where no empirical data are available, the weights methodology can be developed and consolidated with the structural component R&D efforts including consideration of changing requirements for crashworthiness, survivability, maintainability, and component life.

The major thrust of activities over a 20-year period is to improve the weight prediction methods for missions systems, incorporating aircraft configuration such as tilt wing or tilt rotors. In the more conventional types of vehicles the changes in criteria will be considered along with design considerations, such as improved reliability versus minimum weight structures, for up-dating weights methods and improving accuracy. The overall goal is increased accuracy in terms of prediction versus actual roll-out weight of the first vehicle (see figure ST–2). Chart ST–III shows the representative activities that can be undertaken to advance this technology.

MATERIAL ENGINEERING

The application of new and developing materials, both isotropic and anistropic, to aircraft is dependent on the ability to translate advances in basic material properties (i.e., shear strength, fatigue strength, etc.) into improvements in structural components. These improvements may be identified as reduced weight or vulnerability, increased life, safety, reliability, or reduced cost.

Research and development in fibrous composites and high-strength metals has shown very significant gains in such critical parameters as specific strength, stiffness, and fatigue strength. Less progress has been achieved in fracture toughness (i.e., resistance to

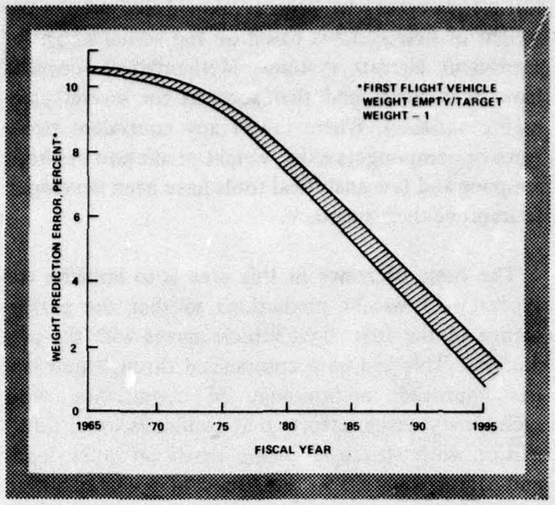


Figure ST–2. Weight prediction improvement goals.

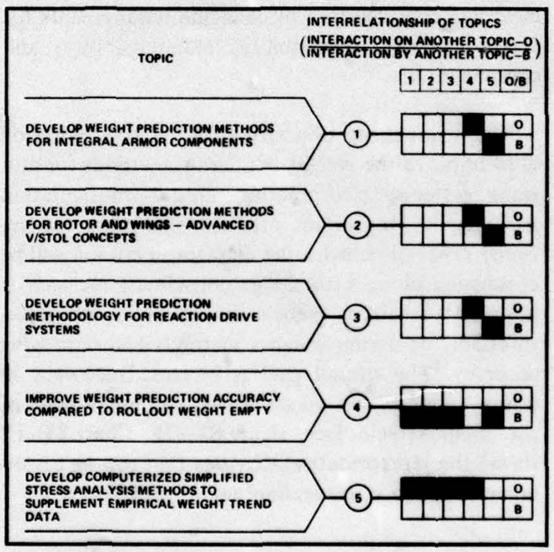


Chart ST–III. Weights Prediction Topics Summary

crack growth). The application of these new materials to actual structures has shown varying degrees of success with cost and lack of confidence being the designer's major barriers to achieving the full potential of the materials.

The basic objective of R&D in this area is to evaluate the physical and mechanical properties of advanced materials for application to Army aircraft structures. These basic material properties must be translated to behavior characteristics of the overall component in terms of fatigue, fracture toughness, impact resistance, corrosion, and environmental degradation. Major considerations in the materials engineering area are efficient joining techniques, fabricability, inspectability, and costs. The cost consideration will not be limited to raw materials but will include manufacture and the effective life cycle cost. Sufficient component development work will be accomplished to provide the required confidence in the application of these materials to primary and secondary structures. This confidence must be gained before the potential of these new materials can be realized in production aircraft systems, which is the primary goal of this effort.

Figure ST–3 shows the expected improvement trends in several key mechanical properties in materials. The expected increased use of composites in aircraft structure is shown in the middle curve.

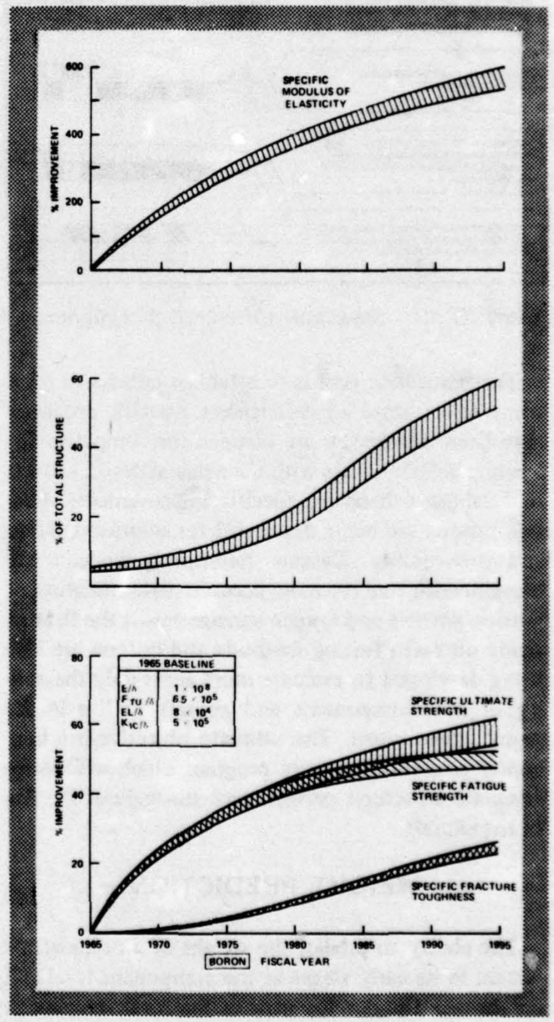


Figure ST–3. Material properties improvement and use goals.

Chart ST–IV shows the interrelated research and development activities necessary to increase the use of new materials that can reduce costs and increase the structural efficiency, reliability, safety, and survivability of new aircraft systems.

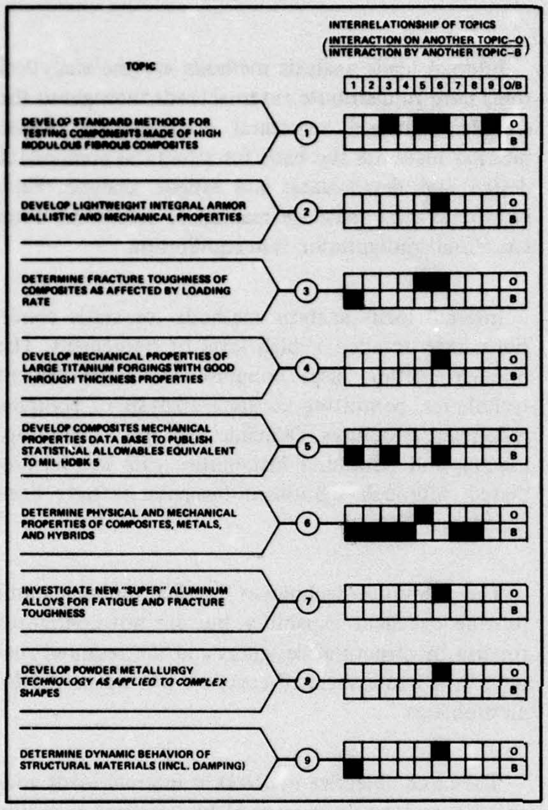


Chart ST–IV. Materials Engineering Topics Summary

EXTERNAL LOADS ANALYSIS

Accurate prediction of design loads that the aircraft will experience in flight or ground operation is required to ensure that the aircraft structure is sized properly to perform the design mission in the operational environment. Accurate external loads are required for structural stability analysis, development of fatigue spectrum, development of internal loads, and stress analysis. The ability to predict these loads is required to assure safety of flight and reduce the expensive engineering changes that result when actual loads measured during flight test differ from original design loads.

The helicopter external loads are extremely difficult to predict since the rotor serves as the lifting system, propulsion device, and pitch and roll control device. The rotor is in a constantly changing aerodynamic pressure field causing a complex and highly cyclic external loads situation. Analytical methods have been developed largely from empirical data for the steady-state dynamic loads on a hovering helicopter. The accuracy of existing methods is reduced as forward speed increases, and the ability to predict loads during maneuvers currently amounts to extrapolating existing measured loads data.

The basic objective of R&D in external loads is to develop improved methods for predicting the loads acting on the vehicle throughout the flight and ground envelope to establish internal loads and stress for structural design. The methodology must consider several degrees of desired precision for loads prediction and is highly dependent on understanding the loads and the technology produced in the aerodynamics and dynamics R&D areas. Also important to the developing technology area are the loads associated with crash conditions, ballistic impact and internal explosions from enemy fire, nuclear blast, and ground handling. Computerized methods must be developed that can provide quick answers for preliminary design loads. For detail design, methods must be developed that will analytically include all of the critical loading combinations and compute the most critical loading conditions for developing internal loads.

Because of the highly cyclic loading conditions caused by rotor rotation, most components are fatigue critical. Since cyclic loads increase sharply with increasing speed and transient conditions, such as maneuvers, these conditions cause the most fatigue damage. For this reason, emphasis will be placed on methods for predicting transient loads. Methods must also be developed for concepts such as tilt rotor and tilt wing vehicles to cover the transition region. Correlation of predicted loads with model data and flight test data must be accomplished to substantiate the analytical methods. Flight loads measurement programs will be carried out with aerodynamic and structural instrumentation to improve the understanding of flight loads and to serve as the data base for correlation of prediction methods.

Figure ST–4 shows the expected improvement trend in external steady-state and transient loads prediction accuracy achievable from R&D in this area.

Chart ST–V shows the interrelated research and development activities necessary to develop improved

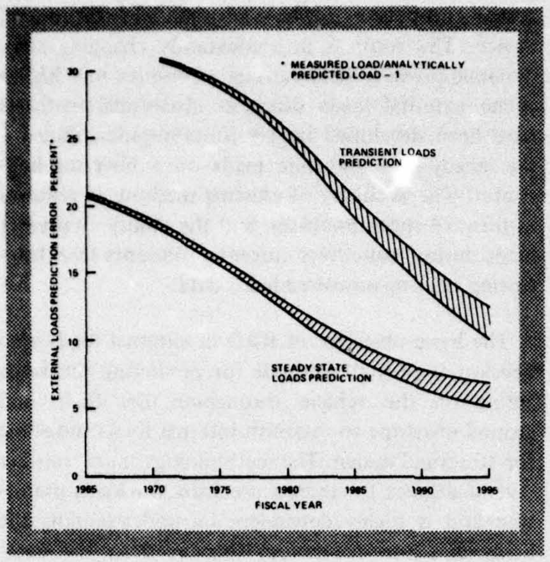


Figure ST–4. External loads prediction improvement goals.

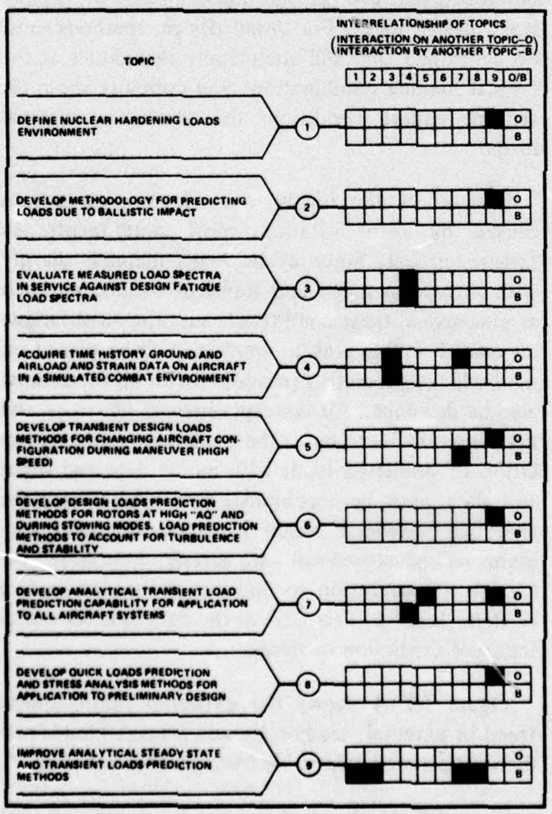


Chart ST–V. External Loads Topics Summary

load prediction methods for all mission systems and provide special load prediction capability to solve specific mission problems.

INTERNAL LOADS ANALYSIS

Internal loads analysis methods are the analytical tools used to distribute external loads throughout the complex internal structural configuration. These internal loads are the basis for structural component design and detail static and fatigue analysis. Each individual load must be reacted to assure the total structural configuration is in equilibrium.

Internal loads analysis methods for static conditions have reached a high level of refinement. The primary method uses computerized finite-element techniques, permitting accurate analysis of complex redundant structures. Dynamic response to vibratory loading and structural instabilities can also be predicted, although significant inaccuracies have been noted.

The analytical techniques in their present status provide excellent capability but are not configured for use by structural designers and the required running time and associated costs are not warranted for all problems.

The basic objective of R&D in internal loads analysis is to extend the present highly efficient analytical techniques developed by NASA and other governmental agencies to handle the problems that are unique to Army aircraft. Simplification procedures can be developed to provide quick and inexpensive capability for the structural designer. The analytical methods can be modified to use the output from the developing external loads technology. Methods can be expanded to include redundant analysis for fail-safety, fracture mechanics considerations, and load distribution in damaged components typical of what would be expected from combat damage.

Figure ST–5 shows the expected increase in use of the advanced analysis methods on Army aircraft design problems. The increased use reflects progress in adapting these programs to the needs of the designer, and in the ability to optimize the structural design for varying loading considerations including battle damage, failures in fail-safe components, etc.

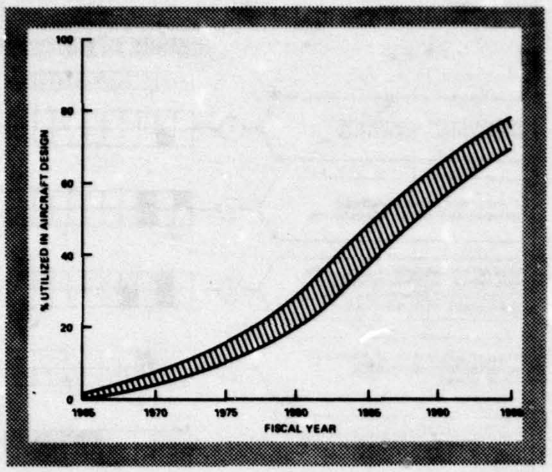


Figure ST–5. Use of improved internal loads methods in Army aircraft design.

Chart ST–VI shows the interrelated research and development activities necessary to expand the internal loads analysis methods for application to Army aircraft and solve specific mission problems.

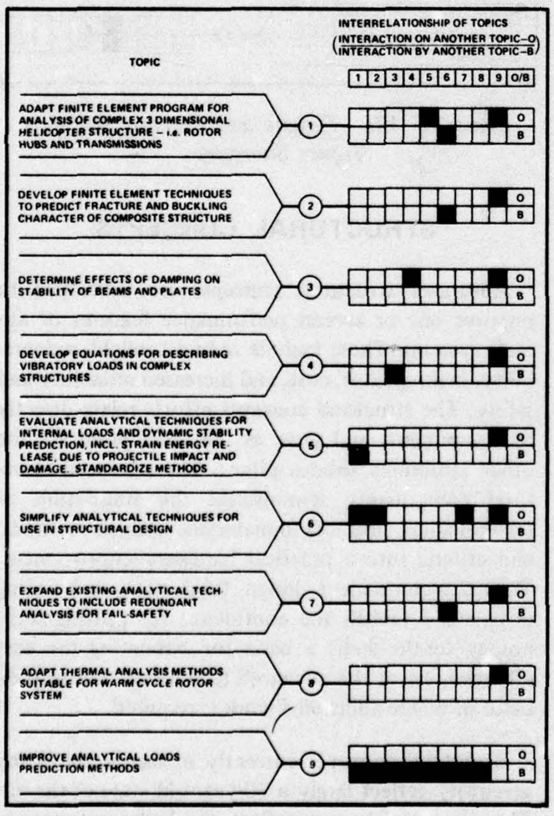


Chart ST–VI. Internal Loads Topics Summary

FATIGUE AND FRACTURE MECHANICS

Primary components of helicopter and V/STOL dynamic systems are largely designed to fatigue loading conditions. Fatigue life is computed on the basis of probabalistically high loads and low fatigue strengths to minimize the potential for catastrophic failure. When predicted fatigue life on this basis has been reached in terms of flight hours, the component is removed and discarded; therefore, components removed for time may have been removed prematurely, having considerably more service life remaining. Conversely, catastrophic fatigue failures have occurred in service because of unexpected causes, such as design errors, manufacturing errors, or misuse.

Fatigue life computation procedures used on Army aircraft vary from contractor to contractor with differing assumptions and degrees of conservatism. Some standardization of analytical methods is needed to evaluate several design configurations and ensure an equitable basis in terms of safety or reliability. This affects structural weight, performance, and costs for the aircraft systems being considered. Service experience indicates that there are enough fatigue failures and extremely limited life parts to cause concern about some of these procedures. Miner's rule of cumulative damage is almost universally used in the industry, although considerable doubt has been cast on its validity in the high-cycle, low-amplitude fatigue environment critical to helicopter and V/STOL concepts.

Service-use spectra, which are the basis for fatigue criteria, are not well-defined and are nonexistent for proposed new aircraft systems such as tilt wing or tilt rotor. The combination of increased performance capability and new mission requirements makes definition of the fatigue design spectrum difficult within the present state-of-the-art. Some progress has been made to develop fracture-control methods by the application of fracture-mechanics theory to predict crack growth in a dynamic loads environment, but not enough to establish fail-safe criteria required for critical components.

The basic objective of R&D in this area is to develop advanced methods of computing fatigue lives of components subjected to a complex, highly cyclic loading environment. The methods must be flexible enough to account for high-cycle and low-cycle spectral loads peculiar to helicopters and rotary wing derivatives. The prediction of structural degradation

will consider not only fatigue to the initiation of a crack, but also propagation of a crack from initial damage point, load cycle by load cycle, to an unstable crack condition. This ability to predict, coupled with fatigue detection devices and cost considerations, will provide for the establishment of realistic fail-safe criteria. Methods for developing accurate fatigue spectra for new aircraft systems can be developed in conjunction with external and internal loads methods to assure safe, reliable systems.

Both the fatigue analysis methods and life substantiation methods now used by the helicopter and V/STOL aircraft industry vary from company to company with differing degrees of success. A program has been initiated which will ultimately lead to establishment of a standard method of Army programs. Fatigue testing will be evaluated to ensure test procedures that produce high-confidence, reliable components, reducing the potential for unexpected failures in the field. Correlations will be made between aircraft performance capability and actual use in the field to provide a rational basis for establishing fatigue spectra in the future. Fatigue monitoring systems are being developed to record aircraft use as it affects the structural integrity and to serve as the criteria for fatigue critical part removal.

Figure ST–6 shows the improvements sought in accuracy of predicting crack propagation to serve in establishing fail-safe criteria. The improvements in the state-of-the-art of fatigue analysis sought are shown on chart ST–VII, which also shows the interrelated activities necessary to realize these improvements.

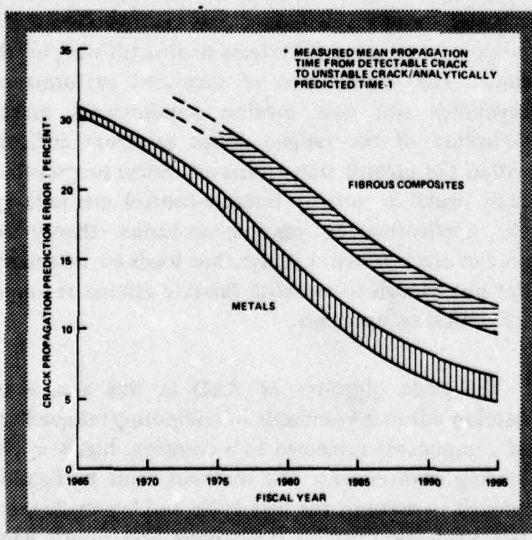


Figure ST–6. Fracture mechanics goals.

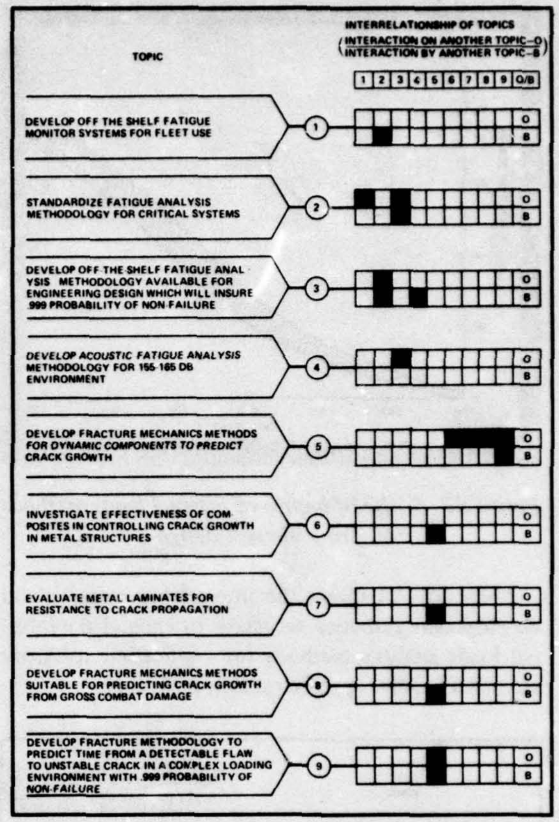


Chart ST–VII. Fatigue and Fracture Methods Topics Summary

STRUCTURAL CONCEPTS

Advanced structural concepts are developed to improve one or several performance features of aircraft systems. These include reduced weight, vulnerability, maintenance, cost, and increased reliability and safety. The structural concepts efforts relate directly to components and serve as the focal point for the other structures subdisciplines. The advanced structural components demonstrate the translation of technological advances in materials, analysis methods, and criteria into a practical hardware improvement. Thus the component design, fabrication, and testing programs establish the confidence for putting technology on-the-shelf, a basis for estimating the cost effectiveness of the advanced technology and an indicator of where additional work is required.

Structural concepts currently in use in the Army inventory reflect largly a 20-year-old state-of-the-art. The concepts do not reflect the latest advances in crash attenuation techniques, ballistic tolerance, or

the efficient use of new materials. Airframes are hand-built from many small detail parts leading to high production costs. Considerable work has been done inhouse and in the industry to apply advanced fibrous composites to structural components. The major efforts to date have been on rotor blades, because of the design flexibility realizable from those materials that can be tailored to specific stiffness and strength needs. Ballistic-tolerant flight control components have been demonstrated. Some studies have been made of applications of new concepts to large fuselage and engine components. Increased confidence is needed to commit the primary structure of developmental aircraft systems to this technology. Uncertainties over the production cost of these new concepts have also limited their use.

The basic objectives of R&D in this area are to demonstrate to an acceptable level of confidence, advanced structural concepts applied to representative hardware components. This effort should effectively use the advancement in the other structures subdiscipline areas as well as safety and survivability, reliability and maintainability, and other related disciplines as applicable. Since this serves as the primary area for putting structures technology on the shelf, it must be a phased program applying basic research accomplishments through design studies to demonstrate concept feasibility. The promising concepts should then go to detail design, fabrication, and test in an advanced development effort. The results of the exploratory development should provide the basis for advanced development and demonstration showing relevance to a specific planned aircraft system or improved capability for an existing system. Because of the combat mission of Army aircraft, fail-safe configurations and combat damage survivability, to include nuclear hardening, are key structural features that will be emphasized as objectives of the structural component concepts.

Specific efforts can include the development of fail-safe structural concepts for the dynamic system as well as the airframe. Advanced composite rotor blades, rotor hubs, and fuselage sections will be designed, fabricated, ground tested, and flight tested to demonstrate the feasibility of these concepts on a component basis to assess the advantages of weight savings, producibility, and potential cost savings. A complete Advanced Structures Technology Demonstrator (ASTD) aircraft will be designed, fabricated, and tested to evaluate the advantages in a total systems application of advanced structure for increased survivability and reliability, reduced weight, size and cost. Figure ST–7 shows expected improvement trends in weight savings in several aircraft subsystems achievable from research and development in advanced structural concepts. The net results of improvements in structural efficiency may not result in weight savings but increased structural capability (i.e., crashworthiness, improved reliability and survivability, etc.) within the existing structural weight fraction. Material and fabrication cost of new concepts may initially increase although life cycle cost will be reduced. Increased production quantities of new materials, coupled with component production experience will, in the near future, reduce the initial cost.

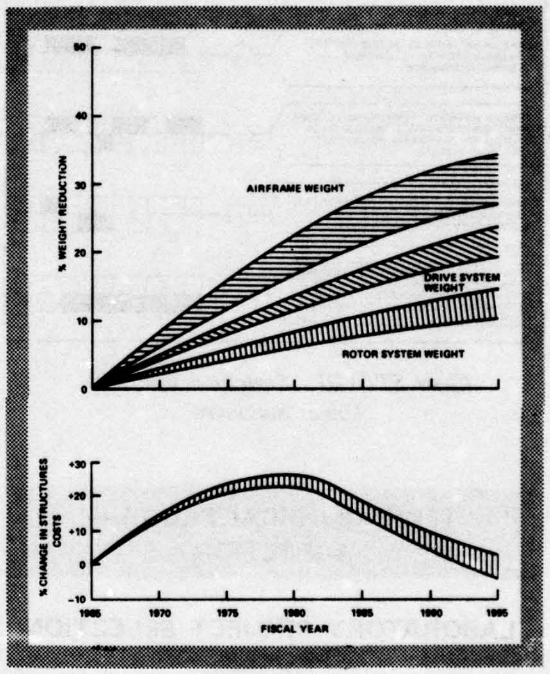


Figure ST–7. Structural concepts goals.

Chart ST–VIII shows the interrelated research and development activities directed toward development of advanced structural concepts, in general, and toward solution of special structural design problems associated with specific mission requirements. It further displays that the hardware components developed reflect the improvements from all of the structures subdisciplines as well as reliability and maintainability, safety and survivability, etc. The mainstream effort is to improve the overall structural efficiency while reducing initial and life cycle costs.

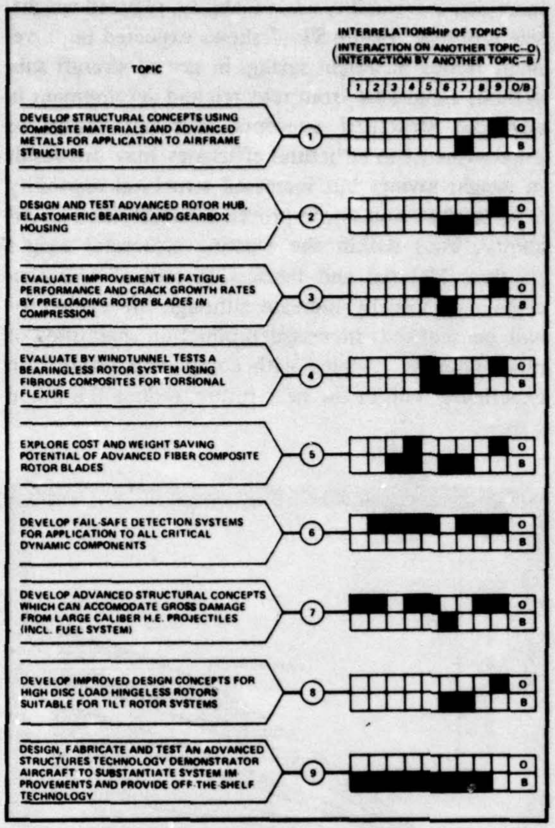


Chart ST–VIII. Structural Concepts Topics Summary

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the structures discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the structures discipline can be established from the near-term quantified achievement goals listed in chart ST–I. The objectives are of two types. First, those which will result in direct improvement of one or several key parameters and second, those which improve prediction capability and produce indirect performance and cost improvements. The near term structures objectives are as follows:

- Develop improved structural design concepts which take full advantage of composite material behavior.
- Increase on-condition parts to 40 percent of total. Reduce low-life parts to 20 percent of total.
- Realize a 10 percent improvement in critical mechanical properties.
- Improve capability to predict steady and transient loads to within ±18 and ±28 percent respectively.
- Improve ability to predict crack growth rates in metals and composites to within ±19 and ±26 percent respectively.
- Realize 15 percent weight reduction in airframe and 8 percent in dynamic systems at reasonable cost.

PROGRAM PRIORITIES

General. Table ST–A presents, in a prioritized listing, the structures technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The structures technology subdisciplines are represented by the following major topical areas:

- *Criteria.* Structural criteria are developed for each aircraft system to describe the procedures to be observed by the designers to insure that structural integrity is built into and maintained in the system. It acts as the overall guideline for most other disciplines.
- *Material Allowables.* Engineering material allowables pertain to the physical and mechanical properties of materials used to transmit forces throughout the aircraft system. These properties are expressed as parameters with a

high probability of exceedance to insure structural integrity in the final product.

- *Internal/External Loads Analysis.* Design loads prediction methods pertain to the ability to accurately predict the magnitude of forces that the aircraft is subjected to in its lifetime. The forces must be defined in terms that insure a low probability of exceedance, and that may be used and verified by the designer through tests. The loads may be externally applied, for example, aerodynamics, inertia, ground contact, or internal, for example, stress distribution through complex redundant structure.

- *Fatigue/Fracture Mechanics.* Fatigue/fracture methods pertain to the ability to accurately predict the ability of aircraft structure to resist fatigue degradation and to be tolerant of structural damage. It is the rational coalescence of materials allowables and design loads methods to insure safe life/fail safe aircraft systems.

- *Structural Concepts.* Advanced structural concepts pertain to the ability to combine the best of the materials and methods described above into new conceptual systems or subsystems with unique capability in terms of reduced weight and cost, increased survivability, maintainability or durability, or a combination of these.

Vehicle Subsystems. Vehicle subsystems, as related to structures technology, are categorized as follows:

- Dynamic lift/propulsion elements – rotors and propellers.
- Auxiliary control elements – tail rotors and control surfaces.
- Nondynamic airframe elements – fuselage, wings, and landing gear.
- Equipment elements – equipment integration.

These are the vehicle subsystems which produce the major structural design requirements and the most impact on structural integrity.

System Effectiveness. In the area of system effectiveness, the primary impact of structures technology is on life cycle costs and vehicle effectiveness. In the life cycle cost area, structures play a key role in development, flyaway and attrition costs; while in vehicle effectiveness, structure is most prominent in determination of vehicle vulnerability, crashworthiness, signature, and maintainability.

Priorities. With reference to table ST–A, the structures subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

Assessment of the priority listing in table ST–A and the near-term objectives listed above indicates that the first major thrust is to develop advanced rotor system concepts to reduce vulnerability due to hostile environment. The rotor system, that is, hub and blades, provides most of the lift/propulsion and control to VTOL aircraft and, at the same time, is

TABLE ST–A
PRIORITIZED STRUCTURES OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Structural concepts	I	• Dynamic lift/propulsion	I	• Vulnerability	I
• Internal/external loads analysis	II	• Airframe	II	• Attrition costs	II
		• Auxiliary control	III	• Signature	III
• Fatigue/fracture mechanics	III	• Equipment	IV	• Crashworthiness	IV
				• Flyaway cost	V
• Criteria	IV			• Maintainability	VI
• Material allowables	V			• Development cost	VII

directly subjected to the worst natural and man-made hostile environment. Service data indicates a great need for improvement in these systems. A weight improvement potential is anticipated in this area, and through application of advanced materials, large strides can be anticipated in damage tolerant design. Basic research efforts and component exploratory development programs have progressed to the point that the next logical step is to demonstrate the potential payoff of this technology through advanced development programs. This payoff will be reflected in increased ballistic tolerance and safety, while reducing radar signature and maintenance. The advanced concepts will permit reduced vehicle life cycle costs resulting from reduced weight, number of parts, and manufacturing manhours.

The second major thrust is to develop advanced airframe system structural concepts to reduce vulnerability due to hostile environment. Service experience clearly indicates the need for this improvement. Although the airframe is not as critical a problem as the rotor system, the potential payoff (15% airframe weight reduction vs. 8% for dynamic systems) is greater and justifies concerted effort in this area.

LABORATORY PROJECTS IN STRUCTURES

INTRODUCTION

Structures technological development effort is directed towards research (6.1), exploratory development (6.2), and advanced development (6.3) to increase knowledge and demonstrate advanced aircraft technology in the structures discipline. This effort is conducted primarily by the AMRDL Langley Directorate at Langley Research Center, colocated with NASA, and the Eustis Directorate at Fort Eustis, Va. The Langley Directorate deals primarily with 6.1 and exploratory 6.2. The Eustis Directorate deals primarily with 6.2 and nonsystems 6.3 work.

Programs at the Langley Directorate are primarily in the areas of internal loads analysis, fatigue, and fracture mechanics. Programs at the Eustis Directorate are primarily in the areas of structural criteria, external loads analysis, materials allowables, and advanced structural concepts.

The distribution of programs between the two directorates is influenced in part by the capabilities of the NASA-Langley Structures Research Laboratory and the structures testing facilities at Fort Eustis.

DESCRIPTION OF PROJECTS

Research in Structures. Project 1F161102AH45-TA III is a basic research effort providing the fundamental structures and materials application technology necessary for demonstration of the significant improvements possible in rotary wing safety, survivability, and mission effectiveness through a viable structures program. The efforts under this project are directed toward the development of analytical techniques for complex structures to include metals, composites, and metals reinforced with composites, as well as to develop the fatigue characteristics of these structures and demonstrate the utilization of these materials on rotary wing aircraft. The fracture characteristics of these materials will also be determined in order to develop adequate fracture control procedures and techniques. These research objectives are accomplished by in-house research programs conducted by the Langley Directorate in joint participation with the NASA-Langley Research Center and by in-house research conducted by Watervliet Arsenal.

Structures Technology. Project 1F262209AH76-TA II is an exploratory development effort to develop and demonstrate the technologies, techniques, and design criteria necessary to provide adequate performance structural design loads, aeroelastic stability, static and fatigue strength, and structural integrity for the Army's rotary wing missions and to improve the capability to analyze and predict these characteristics to existing and future aircraft. This technology will increase the aircraft's availability and survivability as well as provide for improved operational effectiveness and mission capability of Army aviation systems. Research from this project will provide part of the analytical, design, and test techniques necessary for valid prediction and analyses of the performance, structural design loads, aeroelastic stability, static and fatigue strength, and structural integrity, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by conducting analytical, structural, wind tunnel, and flight test investigations. Foreign state-of-the-art trends and potential threats to the present and future material or systems throughout the R&D cycle have been considered.

Advanced Aircraft Structures. Project 1F263211DB41 is an advanced development effort to

develop and demonstrate advanced structures technology, test techniques, and evaluation criteria to provide advanced design concepts and structural components with increased survivability, improved reliability and maintainability, and greater mobility for Army aircraft. Advanced design concepts and composite materials will be evaluated in rotor blades, rotor hubs, landing gears, airframes, and other structural components to provide the necessary data and technology to move into engineering development. Research from these efforts will provide analytical, design, and test techniques for valid prediction and analysis of the structural performance, manufacturability, and structural integrity, thereby increasing the potential of achieving design-to-cost objectives within the Army. These research objectives are accomplished by conducting analytical, structural, wind tunnel, whirl, and flight test investigations. Foreign state-of-the-art trends and potential threats to present and future material or systems throughout the R&D cycle have been considered.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the structures R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 structural R&D efforts are shown in table ST–B. Included in the table is the ratio of the structures efforts to the total 6.1, 6.2, and 6.3 AMRDL R&D efforts.

TABLE ST–B
STRUCTURES TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.1	1F161102AH45-TA III	1112	23%
6.2*	1F262209AH76-TA II	2475	16%
6.3	1F263211DB41	1650	12%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

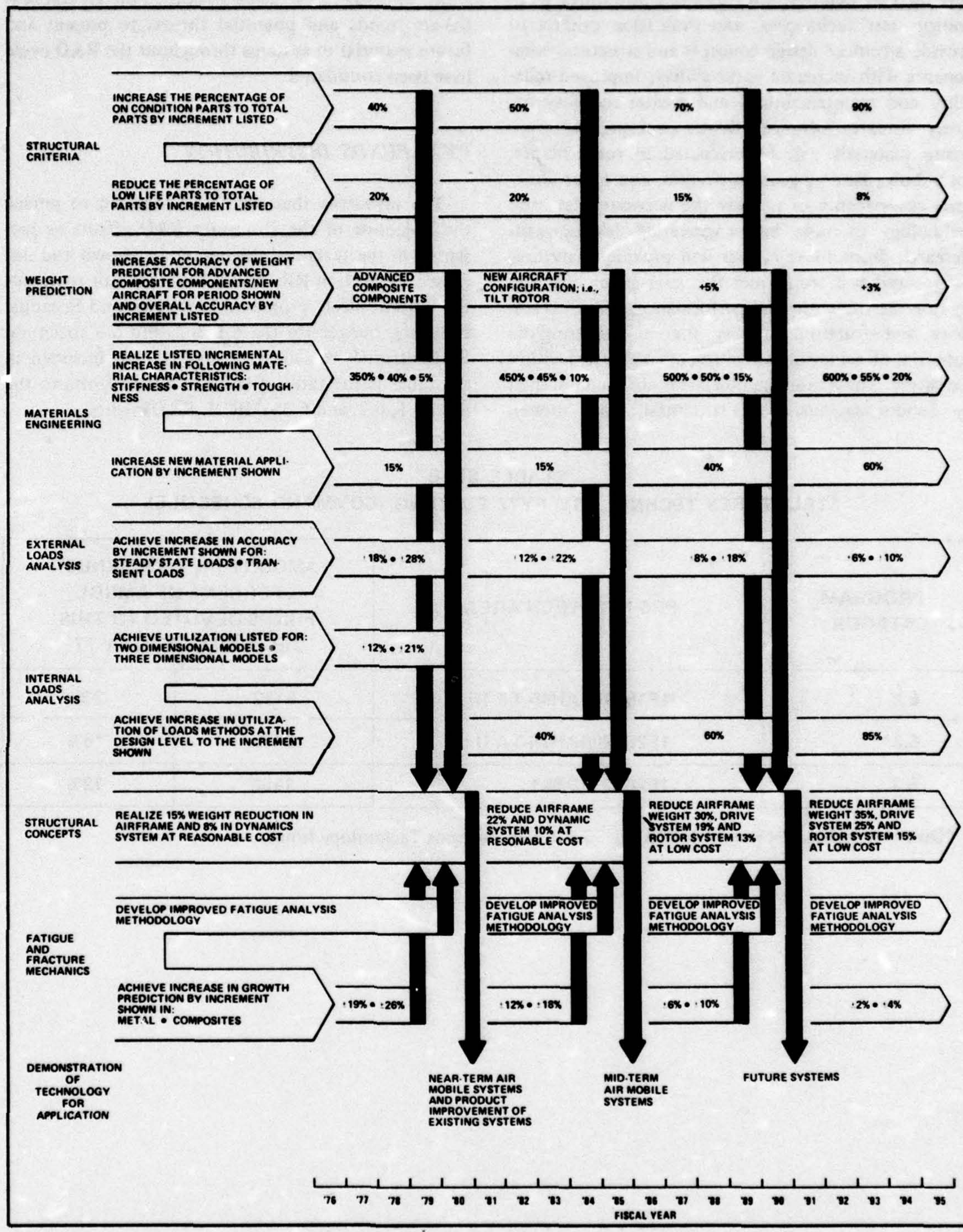


Chart ST–I. Structures Achievement Goals

INTRODUCTION

TECHNOLOGICAL DISCUSSION

GENERAL

AERODYNAMICS

CONTROLS AND ACCESSORIES

MECHANICAL ELEMENTS

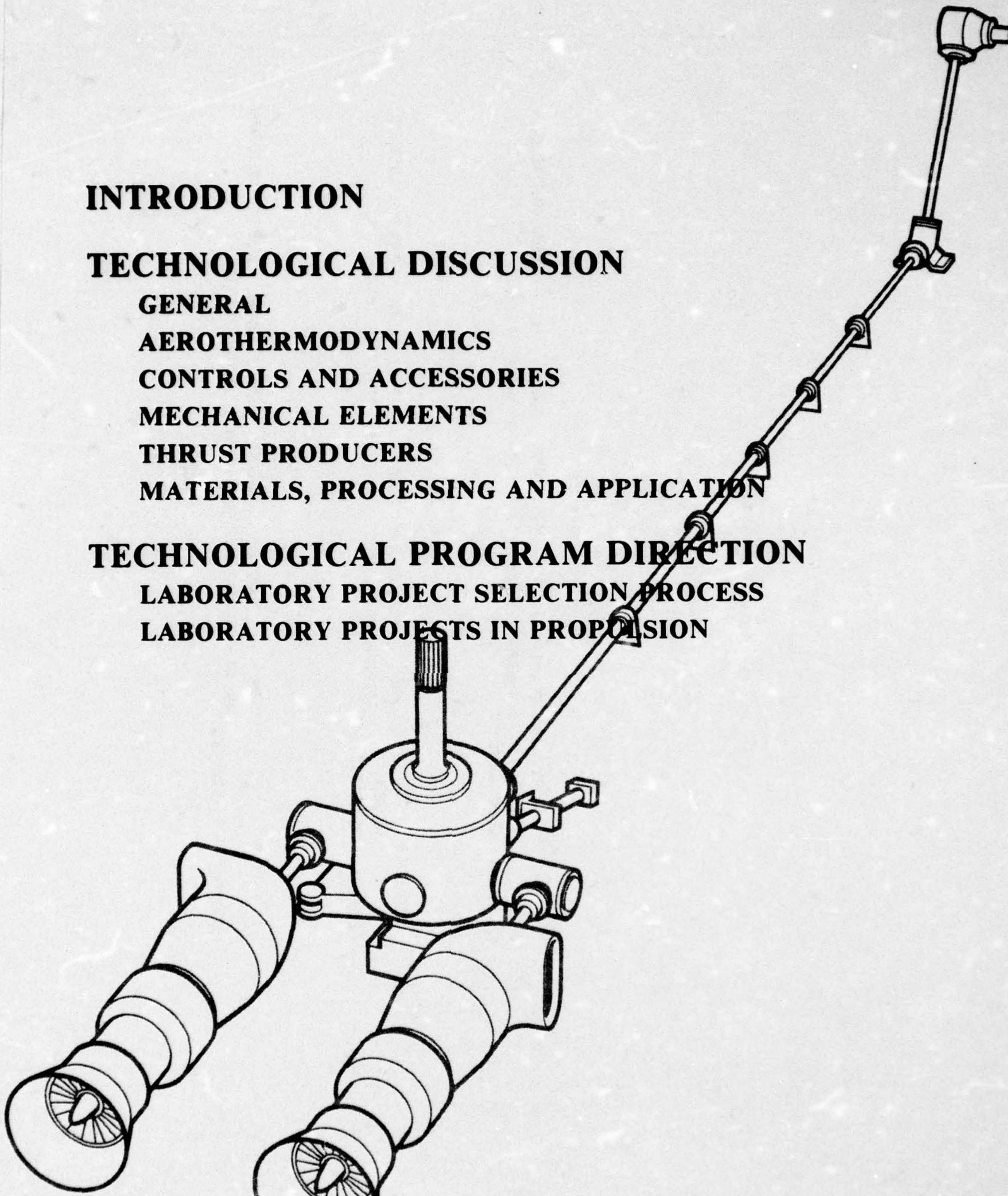
THRUST PRODUCERS

MATERIALS, PROCESSING AND APPLICATION

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS IN PROPULSION



INTRODUCTION

Propulsion system technology provides the mechanisms and processes by which the chemical energy in fuel is converted into forward thrust and/or lift. The process normally involves one or more of the following conversions:

- Chemical energy into heat
- Heat into mechanical energy
- Mechanical energy into thrust and/or lift

The effect of propulsion system technology on the aircraft is profound. Assuming that an engine with adequate power can be provided, the performance, payload, and range of the aircraft are directly related to the weight and efficiency of the propulsion system. Increases in system weight will result in reductions in performance, payload, range, or combinations of the three. Reductions in system efficiency will result in the use of more fuel to perform the mission. In addition to extra fuel usage, the weight of the additional fuel and associated tankage will result in penalties on performance, payload, and range.

The missions and aircraft that constitute Army aviation activities are described in the Airmobile Systems Section of this plan. Since the Army operates in the V/STOL and low subsonic flight regimes, the propulsion systems of major interest are turboshaft and turboprop engines, in sizes of less than 20 lb/sec airflow, with associated drive trains, reduction gearing, propellers, and other thrust producers. Tri-service agreements have established the Army's responsibility for conducting R&D in this area.

The general objectives of propulsion system R&D are to provide the technology for turboprop and turboshaft engines of less than 20 lb/sec airflow and for the associated drive trains, reduction gearing, propellers, and other thrust producers which are:

- More efficient
- Lower weight
- More reliable
- More maintainable
- Lower in cost than those currently available

The R&D activities which result in continued improvement in the characteristics of propulsion systems can be separated into subdisciplines. The principal ones are defined in table PR–A. In addition to these subdisciplines, advanced development effort is conducted in the overall areas of engines and drive trains. The objective is to demonstrate that advances in propulsion and drive train component technology are translatable into improvements in actual aircraft engines and drive trains.

Quantified goals for each subdiscipline are presented in chart PR–I (located at the end of this section). Incremental achievement goals are shown for the 20-year span covered by the Plan. A further discussion of some of these goals is presented later in this section.

The propulsion system for any aircraft has a large impact on the effectiveness of the aircraft and there is considerable interdependence among the various subdisciplines addressed in this section, as well as among the various disciplines discussed separately in this document. The interaction between the subdisciplines of table PR–A is diagrammed in chart PR–II.

TECHNOLOGICAL DISCUSSION

GENERAL

The requirements, characteristics, interrelationships, and rationale for Army aircraft propulsion system technology are presented in this subsection together with a discussion of technological thrust areas.

Small size and an unusual operating environment impose special requirements upon Army aircraft propulsion systems. Advances in technology which have been successfully demonstrated in large, modern turbofan and turbojet engines cannot be directly scaled to the less than 20 lb/sec size, which the Army requires. Innovative technology is required in a number of areas. For example: scaling of multi-stage axial compressors would result in blading which is prohibitively small from the standpoint of manufacturing tolerances and durability, therefore centrifugal compressor stages are usually employed. Similar difficulties are encountered with other propulsion system components. In addition, helicopter transmissions and drive trains are unique. No other vehicle imposes similar input and output speed and torque requirements or similar load carrying requirements.

TABLE PR–A
PROPULSION AND DRIVE TRAIN SUBDISCIPLINE DESCRIPTION

AEROTHERMODYNAMIC COMPONENTS	• **Covers the broad subjects of predicting and demonstrating improved performance of inlet protection systems, compressors, combustors, turbines, and exhaust systems. The primary objectives are reduction in complexity plus improved efficiency and reliability.**
CONTROLS & ACCESSORIES	• **This area includes controls, fuel pumps and metering systems, oil pumps, starters, alternators, and sensors. The primary objectives are reductions in weight, volume and cost plus improved reliability.**
MECHANICAL ELEMENTS	• **Included in this area are bearings, seals, gears, shafting, couplings, clutches, and casings. The development of lighter, less vulnerable, and more reliable elements is a continuing objective.**
THRUST PRODUCERS	• **Covers those elements involved in converting the mechanical energy produced by the engine into thrust for the aircraft, primarily propellers and fans. Primary objectives are improved efficiency and reliability plus lower weight.**
MATERIALS PROCESSING & APPLICATION	• **Covers the application of new alloys or materials possessing improved thermal and mechanical properties and the development and control of the processes employed to produce the material and fabricate parts. Objectives are improvement of system efficiency through increased temperature capability, improved reliability, and reduced manufacturing costs.**

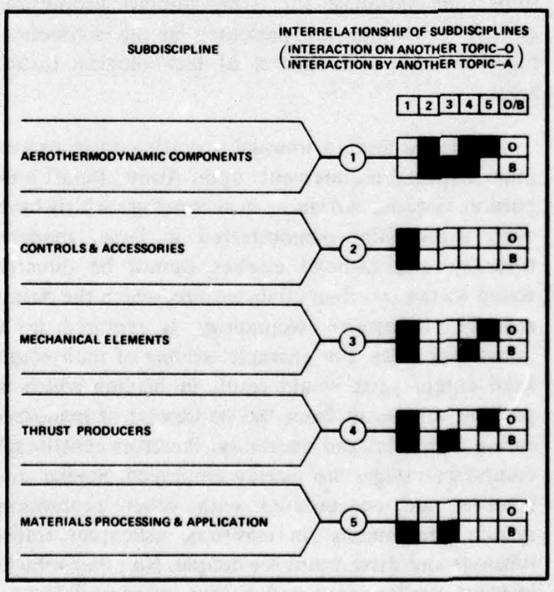


Chart PR–II. Subdiscipline Interaction.

The operating environment imposes a significant demand for innovation. Helicopter propulsion systems are subjected to frequent starts and shutdowns as well as frequent power changes. The system is also subjected to severe and continuous vibration. Operation of aircraft from unimproved areas results in exposure of the propulsion system to large quantities of sand and dust. Low altitude operation exposes the propulsion system to small arms as well as antiaircraft weapons. Innovative technology is required not only to achieve acceptable levels of performance in Army aircraft propulsion systems but to enable them to survive in the Army environment as well.

Figure PR–1 illustrates the relationship between specific power (proportional to engine size and weight per horsepower), specific fuel consumption, and the cycle parameters pressure ratio and turbine inlet temperature for a family of potential gas turbine engine design points. The figure shows that significant improvements in engine performance can be obtained

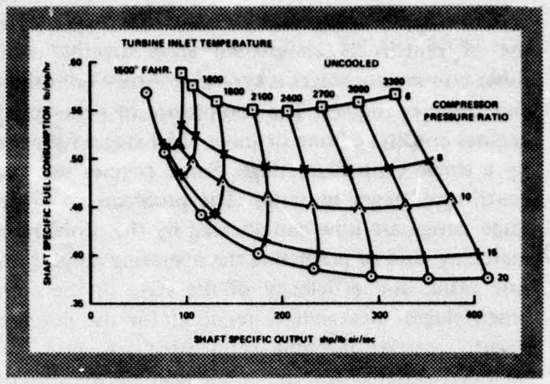


Figure PR–1. Design point performance – SLS.

through increases in pressure ratio and temperature. However, without advances in technology, these improvements can only be obtained at the expense of complication, increased cost, stronger IR signature, added reliability problems, and increased sensitivity to sand and dust.

The data shown in figure PR–2 represents design point performance. Since Army aircraft operate most of the time at part power, careful attention should be given to off design performance. Figure PR–2 illustrates part power performance of two engine cycles. The figure shows that although engine A has slightly better fuel consumption at 100 percent power, engine B has a significant advantage at part power. Selection of cycle parameters should be made only after analysis of the anticipated duty cycle of the engine.

The Army requirement for small engine sizes leads to unique problems requiring innovative technology. Successful refinement and attainment of efficient performance in modern turbofan and turbojet engines in the 200 lb/sec size range cannot be directly scaled down to the less than 20 lb/sec size. Such areas are: centrifugal compressors are often substituted for several very small axial stages; radial flow turbines are often used, rather than small axial turbines; combustors demand special attention to both the configuration and the fuel injection process; controls must be more rugged, smaller, and less complicated. All engine components must be developed toward improved functional performance, with less costly configurations of fewer elements.

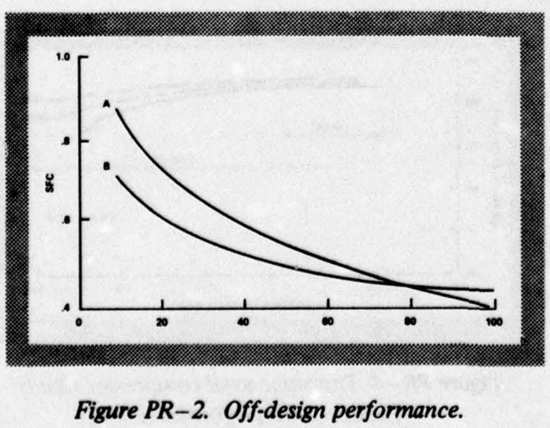


Figure PR–2. Off-design performance.

The development of a serviceable engine embodying advanced technology involves steps subsequent to the development of improved components. A gas generator consisting of a compressor, combustor, and turbine may be assembled and run to demonstrate gas performance and a solution to matching problems. The STAGG (Small Turbine Advanced Gas Generator) program illustrates this phase. Further progress toward a serviceable engine may be made through a demonstrator engine program, in which the desired engine type (turboshaft, turboprop, or turbofan) is built to prove the level of output performance available for a production engine. Recent applications of this technique are the 1,500 hp demonstrator engine, now selected for UTTAS and the new 800 hp ATDE (Advanced Technology Demonstrator Engine).

AEROTHERMODYNAMICS

INLET PROTECTION

Improved resistance to erosion by sand and dust has been accomplished by the use of particle separators ahead of the compressor, preferably integral with the engine. The operating time prior to destructive erosion tends to be the reciprocal of the fraction of particles left in the inlet air after separation, and a tenfold increase in operating time now appears possible. This separation is accomplished at the expense of approximately one percent of the engine power, caused by the pressure loss in the separator. Research is directed toward improving separator effectiveness while reducing the pressure drop and power loss, and decreasing the separator size and scavenge flow required. The basic resistance of the engine, principally the compressor, to sand and dust erosion can be improved by using erosion resistant materials, and by the application of coatings more resistant than the parent metal. Research in both materials and coatings will provide greater engine life in the sand and dust environment.

An integrated inlet protection system is in the last stages of engineering development as part of the T700 engine. During the course of the development program, a problem was encountered with scavenge system durability. As a result, an exploratory development effort is currently underway to demonstrate improved durability scavenge system concepts. This effort, along with continuing materials and coatings research, constitutes the current activities in this subdiscipline. Planned future work includes advanced development of an inlet protection system as part of an 800 hp ATDE; continuing materials and coatings research; and initiating exploratory development to investigate advanced separator system concepts.

COMPRESSORS

Centrifugal Compressor–Single Stage. The attainment of high pressure ratios in one centrifugal compressor stage, replacing several axial stages, promises major improvements in simplicity, cost, and ruggedness of the small engine. At present, the efficiency of the centrifugal stage (and in some cases its surge-free operating range) is less than desired. The improvement of these deficient characteristics requires research into the nature of the flow field in the impeller inducer, the impeller, the vaneless discharge passage, and the diffuser. Location and definition of the losses and the factors causing surge will assist in the development of compressors having reduced losses and a wider operating range. It is essential that research in this area be coupled with the derivation and use of analytical methods covering three-dimensional flow phenomena in curved passages. Figure PR–3 presents a trend in centrifugal compressor pressure ratio and efficiency.

Centrifugal Compressor–Combined Stages. The use of centrifugal compressor stage together with other compressor stages is typical in Army turboshaft and turbojet engines. The compressor of many small engines consists of one or more axial stages followed by a single centrifugal stage. Some engines use two centrifugal stages in series. The problems of single-stage design are now complicated by the problem of matching, and of predicting the operating range, pressure ratio, and efficiency of the stage or the combined stages. Research is required for the development, correlation, and refinement of analytical methods suitable for the prediction of the characteristics of combined stages. Further research is required to determine the optimum division of work between the individual elements in the combined compressor assembly.

Axial Compressor. Multistage axial compressors are commonly used in conventional large turbofan and turbojet engines. Small engines use the axial-plus-centrifugal configuration to avoid impractically small parts (such as blades), and to obtain improved ruggedness, cost, and resistance to sand and dust. The type of axial stage most suited to the small engine is characteristically a high flow, transonic design with good efficiency and a wide operating range. Research is required to improve the efficiency and operating range of current axial stage designs, and to provide an accurate analytical method for predicting and analyzing stage performance. Figure PR–4 presents the state-of-the-art in transonic axial stage pressure ratio and efficiency.

HEAT EXCHANGERS

Heat exchangers are used in regenerative gas turbines to transfer waste heat from the engine exhaust

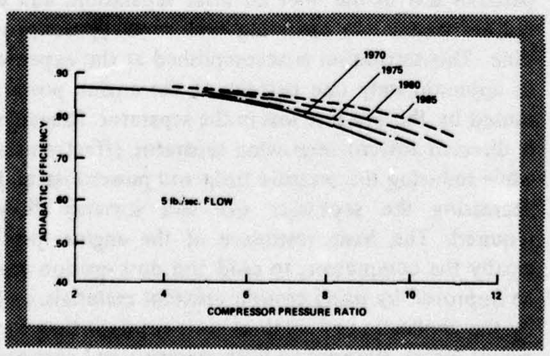


Figure PR–3. Centrifugal compressor trends (design point performance).

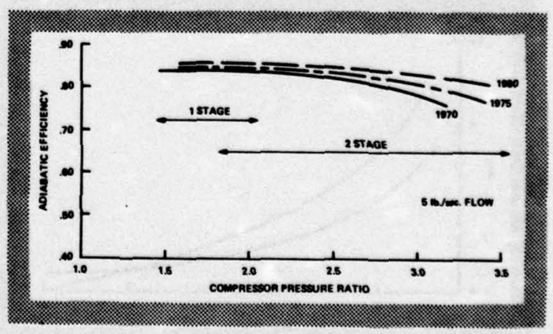


Figure PR–4. Transonic axial compressor trends (design point performance).

to the air entering the combustor. This reduces the amount of fuel required in the combustor. The reduction in fuel consumption is substantial, especially at reduced power settings. However, with existing technology, the weight and cost penalties associated with these heat exchangers outweigh their fuel savings in aviation applications. Improved technology, especially in materials and fabrication processes, plus the increasing cost and less certain availability of fuel may change this situation in the future. Thus heat exchanger research will continue with particular emphasis on cost reduction.

Combustors for small engines cannot be designed by direct scaling from large combustors, since the combustion process cannot be scaled, and small engines often require a reverse flow, or folded, or radial flow combustor rather than the straight-through. Research is required to improve liner cooling methods, fuel injection techniques, methods of pattern and hot-spot control, and emissions. Research in combustors will be coordinated with the task of minimizing undesirable exhaust components in order that improvements in performance will be combined with reduced levels of pollution. Research is also needed to provide improved liner materials, possibly non-metallic, having greater tolerance to high temperature and a lower cooling requirement.

Areas of projected future effort in combustor R&D include:

- Improved pattern factor to maintain turbine vane life at elevated turbine inlet temperature.
- Primary zone radiant heat reduction.
- Improved fuel atomization.
- Fuel contamination investigation.
- Experimental investigation of very small combustors.

The primary objectives of current and planned future efforts are to:

- Improve turbine vane life.
- Reduce time and cost associated with combustor development.

TURBINES

Axial Turbines. The use of axial turbines in small engines has been complicated by factors not subject to scaling, such as tip clearance, minimum wall thickness in hollow blading, and cooling. Research is required in these areas, as well as in methods for the prediction of metal temperature distribution and gradients, stress magnitude and distribution, internal cooling, and low-cycle fatigue. Research is needed in the field of turbine materials and fabrication processes, covering basic material properties and fabrication methods for the practical production of integral blade and wheel assemblies, both with and without cooling air passages.

Radial Turbines. The use of radial turbines in small engines is expected to increase, particularly in combination with radial compressors. Advantages include a reduction in the number of mechanical elements and in cost. Research is required to develop predictive techniques for metal temperature and heat transfer, and for stress analysis. The use of radial turbines at high temperatures requires research in the configuration and effectiveness of cooling arrangements, together with investigation into the materials and fabrication problems created by the high temperature and cooling. Research should address the problems of high specific output and the cooling of small rotors. Trends in turbine efficiency and inlet temperatures are predicted in figure PR–5.

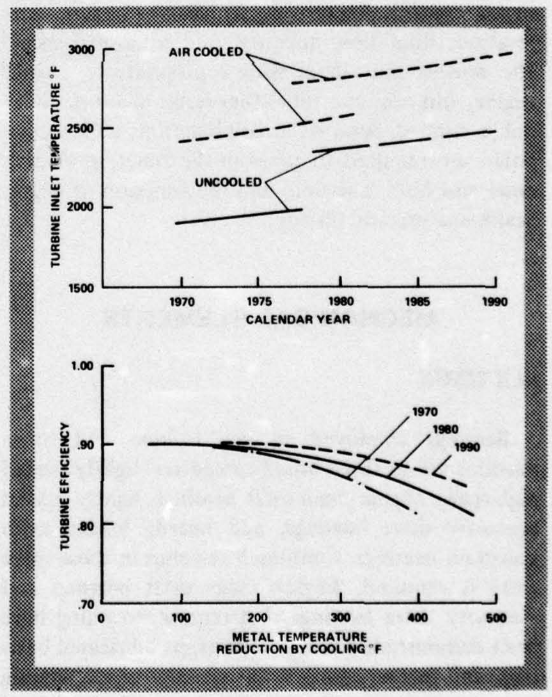


Figure PR–5. Turbine inlet temperature.

CONTROLS AND ACCESSORIES

FUEL CONTROL

Fuel controls for small gas turbines have been relatively heavy, costly, and limited in function. Research is required to provide improved function, such as closed-loop surge protection rather than scheduling, engine health sensing and display, and direct sensing and display of compressor-turbine inlet temperature. New technology in electronics, fluidics, pyrometry, pressure transducers, and computers must be explored and applied.

FUEL PUMPS

Fuel pumps require functional improvement. Fuel pumps currently are limited in their capacity to pump a mixture of vapor and liquid, and must be supplied with fuel under pressure by boost pumps. Research is required to improve the vapor tolerance, provide a suction capacity that eliminates the boost pump, and reduce the size by increasing the rotational speed toward gas generator shaft speed.

SENSORS

Sensors are required for new, closed-loop type engine controls, to provide signals of pressure, temperature, fluid flow quantity, and rotational speed. The sensors must have sizes appropriate to a small engine, and response times that result in a functional, stable control. Sensors, in combinations with a computer, are required to perform the function of diagnosis and fault isolation, and the function of engine health analysis and display.

MECHANICAL ELEMENTS

BEARINGS

Bearings employed in gas turbine and transmissions fall in three broad categories: lightly loaded high-speed engine main-shaft bearings, lightly loaded accessory drive bearings, and heavily loaded main gear-train bearings. Continued research in these three areas is required. Engine main shaft bearings and accessory drive bearings that require no oiling have been demonstrated in the form of gas lubricated bearings, and further research has promise of eliminating the gas turbine lubrication system. Foil-type air bearings and hybrid bearings are candidates with similar potential. The acceptance of high DN values (above 2×10^6) by rolling contact bearings in uncertain and warrants research to determine whether compliant rollers or hollow balls or rollers will extend the DN range of conventional bearings. Research in heavily loaded bearings is required to find new bearing materials that will accept heavier unit loadings and will permit operation at higher temperatures without performance degradation. Lubricants capable of higher temperature operations are desired, since this will lead to lighter and more compact lubrication systems.

Continued effort on all rolling contact bearings is mandatory in the field of correlating bearing life with load and speed. The progress in elimination of infant mortality must be continued, and the factors contributing to random behavior must be determined and eliminated. Research is required to determine whether present "clean steel" (CEVM for example) can be improved to further reduce infant mortality, and change the slope of the life versus load curve. Research in materials must also be aimed at determining combinations of raceway, ball or roller, and separator that will survive interruption or loss of lubricant.

GEARS

Current practice in gearing design consists of using carburizing steel such as AISI9310, which provides a hard surface to carry high contact stresses and a tough core to resist bending fatigue. Lubrication and surface treatment are employed to inhibit scoring. Gear tooth proportions and unit loadings result in conservative bending stresses and initial failure in pitting or scoring will occur as excess loads are applied.

Areas of needed research to provide improved gearing are:

- Investigate new gear materials having higher allowable unit loadings than present materials.
- Investigate the basic mechanism of scoring including the behavior of the lubricant film and surface treatment.
- Investigate tooth forms with greater bending strength and lower contact stresses.
- Study improved lubricants capable of operation at higher temperatures and unit loading.

SEALS

Contact-type seals operating at high rubbing speeds have been erratic in performance, and limited in their tolerance to high temperature, high speed, and high pressure. New concepts must be developed, such as liftoff face seals, that will function consistently and properly under the conditions found in modern gas turbines and transmissions. Further research is required in large lubricant air seals that separate large pressure differences both with and without lubricant on one side, to provide a seal having low air leakage, zero oil leakage, good tolerance to transient rubbing, and infinite life consistent performance.

CLUTCHES

Provision for engine failure or fuel runout has been made in helicopters by driving the rotor system through an overrunning clutch, thus eliminating the torque drag of a dead engine and avoiding a major performance loss during partial-engine or autorotating flight. Normally overrunning clutches have been designed to operate at speeds of 2000 to 6000 rpm and were located at the first or between the first and second gear reduction stages in order to eliminate high speed problems. This has resulted in heavy, massive designs. From the standpoint of weight and size, it is desirable to locate the overrunning clutch at the high speed engine output. Clutches suitable for operation at gas turbine shaft speed have been developed, but they have been erratic in function and have had limited life overrunning, with high oil flow and heat rejection. Improved technology must be developed to correct deficiencies in current sprag clutches, and to investigate new concepts.

DRIVE TRAIN STRUCTURE AND ACCESSORIES

A large fraction of the drive train weight consists of housing structure, accessory drives, mounting structure, lubrication system, rotor brake, and related elements auxiliary to the main gear train. Substantial prospects of weight and cost reduction lie in these areas, and require investigation. Such areas are: housings may be simplified and lightened by the use of ceramic parts and by providing a wrought structure to carry loads with a light nonmetallic shell to contain lubricant; the development of a lubricant capable of use at higher temperatures provides the opportunity to house the lubricating system inside the transmission and eliminate external cooling; high-speed accessories, and their associated accessory drives, will reduce weight and size; a wet rotor brake provides more unit energy storage than a dry one. Research in the auxiliary areas of the drive train will reduce weight, cost, vulnerable area, and maintenance requirements.

TECHNOLOGY TRENDS

Trends in gear loading, bearing loading, and transmission weight fraction are presented in figure PR–6.

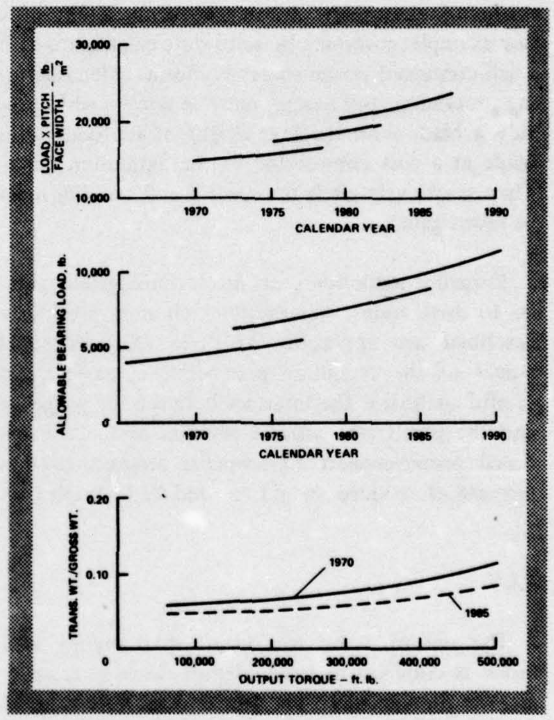


Figure PR–6. Technology trends – mechanical elements.

THRUST PRODUCERS

GENERAL

The term "thrust producer" categorizes the device with which the power developed by the gas generator is converted into thrust. The gas generator is presumed to deliver shaft power by the addition of a power turbine.

PROPELLER AND REDUCTION GEAR

Propellers, with their associated accessories and governing systems, have assumed a variety of configurations: constant-speed, feathering, reversing, acceleration-sensitive-governing; aluminum, steel, fiberglass blades; fluid-deiced, thermally deiced. Advances in propeller technology have been paced by propeller use, which now is confined to a small and shrinking fraction of the military fleet, with a consequent diminished level of activity and progress.

Research on propellers is required to provide simpler and more reliable configurations. The application of elastomeric bearings to blade retention is one example; governing by solid-state electronics with a self-contained power source is another. Manufacturing processing, and design, must be developed to provide a blade with the low weight of the composite blade at a cost comparable to the aluminum blade. The use of cycle pitch for control and stability must be investigated.

Propeller reduction gears are technologically similar to drive trains, and the research areas previously described are applicable to them. An additional aspect of the reduction gear requiring review and careful analysis is the interface between the propeller and the gear train, where a revision of the conventional propeller-shaft to propeller arrangement has promise of reduced weight and reduced complexity.

FAN

The use of a fan to convert shaft energy into thrust is common in large engines. Such an arrangement is flexible, since the flow and pressure ratio of the fan may be selected to match a vehicle requirement, and the fan is normally used to supercharge the gas generator and increase its ability to generate available energy. Thus, a gas generator with a 3000 hp rating is a separate unit may actually drive a 4000 hp fan simply by increasing fuel flow to match the increased inlet density.

The flexibility of the fan-gas-generator is unique. It can be used as a conventional direct drive fan engine to provide thrust at high speed; a source of warm pressurized air for a rotor reaction drive; a high bypass fan, with reduction gearing, to supply thrust at low speed; a convertible fan-shaft-power engine to provide either shaft power or thrust; or a thrust source, with variable pitch, suitable for a fan-in-fin or fan-in-fuselage antitorque system.

Research on fan components is required to provide:

- Improved prediction techniques for blade natural frequencies and stresses.
- Variable pitch mechanisms, materials and processes possessing satisfactory resistance to sand and dust erosion.
- Materials and manufacturing methods resulting in blades of lower weight and increased durability.

MATERIALS PROCESSING AND APPLICATION

METALS AND ALLOYS

Refractory metals (niobium, molybdenum, tantalum, tungsten, osmium, iridium) have had promise of improved strength at high temperature, for use in turbine blades, but in the pure form have been inappropriate because of low ductility and poor resistance to oxidation. Research is required to develop alloys of these basic metals to correct their brittleness and susceptibility to oxidation, and to develop self-healing, high-temperature-resistant coatings.

NONMETALLIC MATERIALS

Silicon nitride and silicon carbide have properties that provide potential for higher temperature operating capability, lower component costs, and lighter weight. Further research is required to improve ductility, possibly by alloying or by the use of a tough matrix, before the ceramic material becomes practical.

Ceramic materials, such as the oxides of aluminum, magnesium, titanium, and zirconium, have properties suggesting their use as a high-temperature structure, but research is required to increase their ductility while maintaining high strength to apply them to severe usage such as a turbine blade. The use of ceramics for high-performance heat exchangers, particularly the periodic type, requires research that will improve the specific heat and the thermal conductivity of the material. Additionally, the high strength silicon nitride and silicon carbide ceramics

considered suited for turbine use have lower thermal expansivity values than the metals currently in use in turbines. Research is required to develop methods of mounting or joining ceramics to metallics.

COATINGS

Protective coatings allow the use of some high-temperature alloys in applications otherwise barred by poor resistance to oxidation or sulphidation. Research on improved coatings is required to provide protection at higher temperatures for both outer and inner surfaces of turbine blades and disks.

CASTING

The fabrication of air-cooled turbine vanes, blades, and wheel-and-blade assemblies is normally accomplished by casting. In addition, certain complex engine housings and transmission housings are cast. Research is required to improve the capability of casting complex internal passages, and improving the material properties of the cast pieces, while increasing the foundry recovery and reducing the cost of the parts.

INTEGRAL ASSEMBLY FABRICATION

The problem of fabricating integral wheel-and-blade assemblies, and complex shapes of radial compressor impellers, has resulted in attempts to use several methods of manufacturing that avoid the expensive "machined-all-over" method. Promising processes include bi-casting, powder-forming and sintering, and plastic extrusion. Research on these fabrication techniques must be conducted to achieve lower costs.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the propulsion discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in this selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the propulsion discipline can be established from the near-term quantified achievement goals listed in chart PR–I. Specifically, the near-term objectives are:

- Demonstrate improved engine technology compared to current production engines in the 800 shp class as follows:
  - Reduce fuel consumption by 20-25%
  - Increase specific power by 40-60%
  - Reduce vulnerable area by 40-50%
- Develop improved drive train technology which will:
  - Reduce weight by 20%
  - Increase MTBR by 100%
  - Reduce production cost by 20%
  - Improve survivability and vulnerability
- Reduce propulsion system costs
- Demonstrate engine components utilizing advanced system components
- Establish requirements for system design and development

PROGRAM PRIORITIES

General. Table PR–B presents, in a prioritized listing, the propulsion technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The propulsion technology subdisciplines are represented by the following major topical areas:

- *Aerothermodynamic Components.* This area covers the broad subjects of predicting and improving the performance of compressors, combustors, turbines, inlet systems, and exhaust systems, leading to higher pressure ratio per stage and reduced specific fuel consumption.

- *Controls and Accessories.* This area includes fuel nozzles, fuel pumps, and fuel metering, with emphasis upon development of more accurate and compact accomplishment of all required functions.

- *Mechanical Elements.* All power transmission components are included in this area; such as bearings, gears, cases, shafting, clutches, brakes, and seals. The development of lighter and more reliable elements is a continuing R&D goal.

- *Thrust Producers.* This area covers the elements involved in converting shaft horsepower into propulsive effort, and includes propellers, fans, and associated components.

- *Materials Processing and Application.* This topic is concerned with the development of improved high-temperature materials and advanced fabrication methods for these materials.

Vehicle Subsystems. Vehicle subsystems, as related to propulsion technology are categorized as follows:

- Power transmission
- Gas generators
- Inlet/exhaust systems
- Power turbines
- Drive shafting

System Effectiveness. System effectiveness refers to the characteristics of the vehicle of which the propulsion system is an integral part. The description of these elements are as follows:

- *Performance.* Encompasses speed, endurance, range, and ability to operate in an adverse environment.

- *POL Requirements.* Covers the logistics of maintaining operations when located at a remote site and is also included as a major element of operating costs.

- *Cost.* Covers acquisition, operating, and total life cycle costs.

- *RAM.* Primarily, RAM is the freedom from scheduled and unscheduled maintenance or repair but, where necessary, easily maintainable.

- *Vulnerability.* The susceptibility of the system to battle damage which results either in failure to perform a mission, long-time inactivation for repairs, or loss of vehicle.

- *Safety.* Encompasses the entire safety and survivability field with emphasis on propulsion caused problems; that is, engine stoppage, fires, etc.

Priorities. With reference to table PR–B, the propulsion subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority – Roman Numeral I, representing the highest priority.

TABLE PR–B
PRIORITIZED PROPULSION OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Aerothermodynamic components	I	• Power transmission	I	• Performance	I
		• Gas generators	II	• POL requirement	II
• Thrust producers	II	• Inlet/exhaust systems	III	• Safety	III
• Materials processing and application	III			• Cost	IV
		• Power turbines	IV	• Vulnerability	V
• Controls and accessories	IV	• Drive shafting	V	• RAM	VI
• Mechanical elements	V				

MAJOR THRUSTS/RATIONALE

The AMRDL major technical thrust for propulsion R&D are as follows:

- Reduce fuel consumption
- Improve heat transfer elements of the aerothermodynamic technology to reduce engine size, weight, and fuel consumption.
- Reduce IR signature and vulnerable area.
- Reduce propulsion system life cycle costs and reduce vulnerability to engine foreign object damage.

The major thrust of propulsion R&D effort is to improve V/STOL aircraft engines and drive trains by reducing size, weight, vulnerable area, cost and fuel consumption while improving reliability, maintainability, and survivability. Reducing the size, weight, and cost of engines and drive trains is important for the attainment of overall system objectives. It allows more power to be installed in an aircraft which improves maneuverability, engine out performance, and overall mission performance. It also compensates for the performance, cost, and empty weight penalties associated with improving IR signature, reliability, maintainability, survivability, vulnerability, and crashworthiness.

The application of aerothermodynamic technology to the improvement of heat transfer components has a powerful leverage in the improvement of the output and efficiency of gas turbine engines and thus, vehicle performance and POL requirements. Substantial improvements in fleet effectiveness and in specific vehicle capability will follow from this thrust.

The reduction of propulsion system costs is the result to be expected from an improved knowledge of costing factors, and from the attenuation of foreign object damage provided by efficient particle separators.

LABORATORY PROJECTS IN PROPULSION

INTRODUCTION

Technological activities in propulsion and drive trains include basic work on internal flow and the behavior of mechanical devices, as a 6.1 effort; the development and test of components of power devices and of drive trains, as a 6.2 effort; and demonstration of successful components of propulsion and drive trains in assemblies, including rig testing and flight testing, as a 6.3 effort. All 6.1 activities, and some 6.2 activities, are conducted by the Lewis Directorate of AMRDL, colocated with the Lewis Research Center of NASA. Many 6.2 activities and all 6.3 activities are conducted by the Eustis Directorate of AMRDL.

DESCRIPTION OF PROJECTS

Research in Propulsion. Project 1F161102AH45-TA II consists of basic research, conducted jointly with NASA, aimed at advancing the technology of propulsion and drive trains. The work is directed toward the solving of special problems involved in the development of small gas turbines, and the investigation of advanced concepts in mechanical devices employed in drive trains.

Propulsive Technology. Project 1F262209AH76-TA III is an exploratory development effort providing the technology necessary to advance development of propulsion systems and drive trains having higher effectiveness than existing systems. This work is accomplished by the development of components with improvements in efficiency, weight, size, cost or serviceability. Investigations have been divided into two work areas. Work area I covers engine components and work area II covers other propulsion components. Activities normally encompass analysis, design, fabrication and test of components such as inlet separators, compressors, combustors, turbines, accessories, transmissions, gears, clutches, couplings, bearings, and thrust producers.

Demonstrator Engines. Project 1G263201D447 provides validated technology for small engines. Advanced component technology from funded (6.2) programs, and from industry-sponsored IR&D programs will be incorporated into advanced gas generators and/or experimental engines for test or demonstration. This work is conducted under contracts by Eustis Directorate, AMRDL.

Propulsion Components. Project 1G263201DB72 provides validated technology for advanced transmission systems and thrust producer concepts. Advanced component technology from exploratory development (6.2) programs and from IR&D programs is used to design, fabricate, and test advanced drive train and thrust producer concepts. This work is conducted under contracts by Eustis Directorate.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the propulsion R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1, 6.2, and 6.3 propulsion R&D efforts are shown in table PR–C. Included in the table is the ratio of the propulsion efforts to the total 6.1, 6.2, and 6.3 AMRDL R&D efforts.

TABLE PR–C
PROPULSION TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.1	1F161102AH45-TA II	1014	23%
6.2*	1F262209AH76-TA III	2895	18%
6.3	1G263201D447**	3420	26%
	1G263201DB72	800	6%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

**Based on Command Schedule dated 16 April 1976

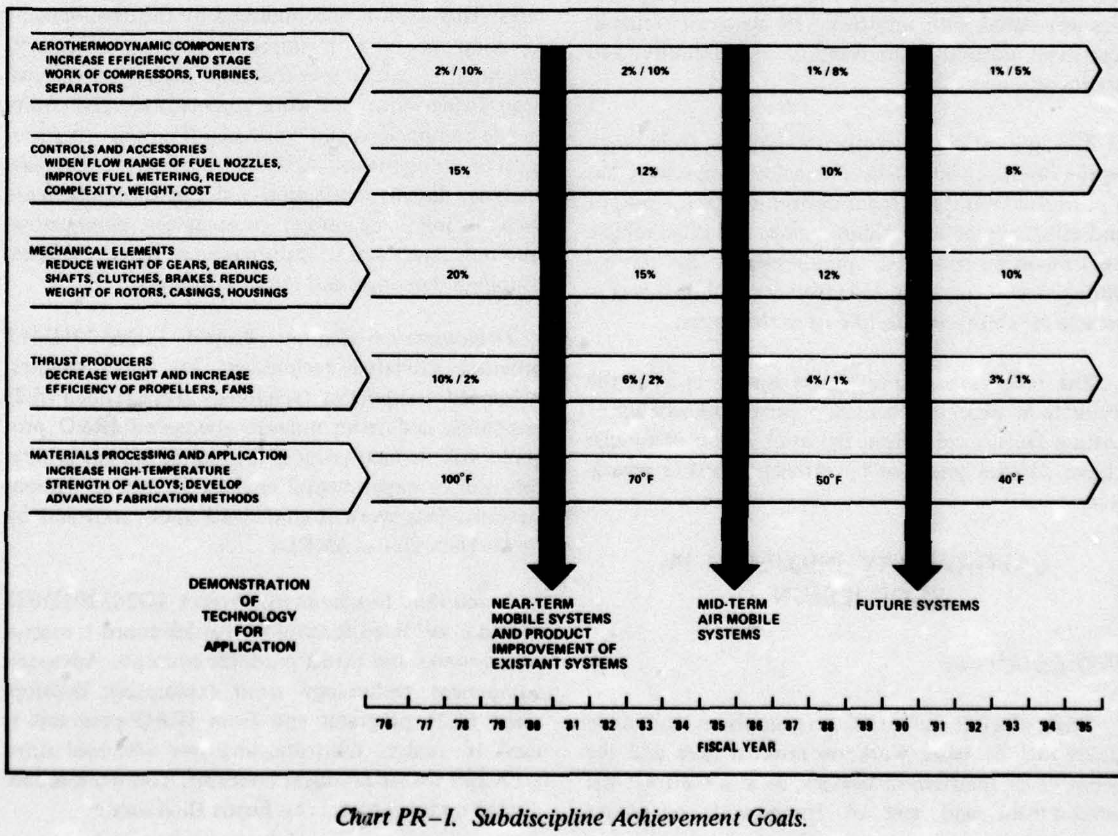
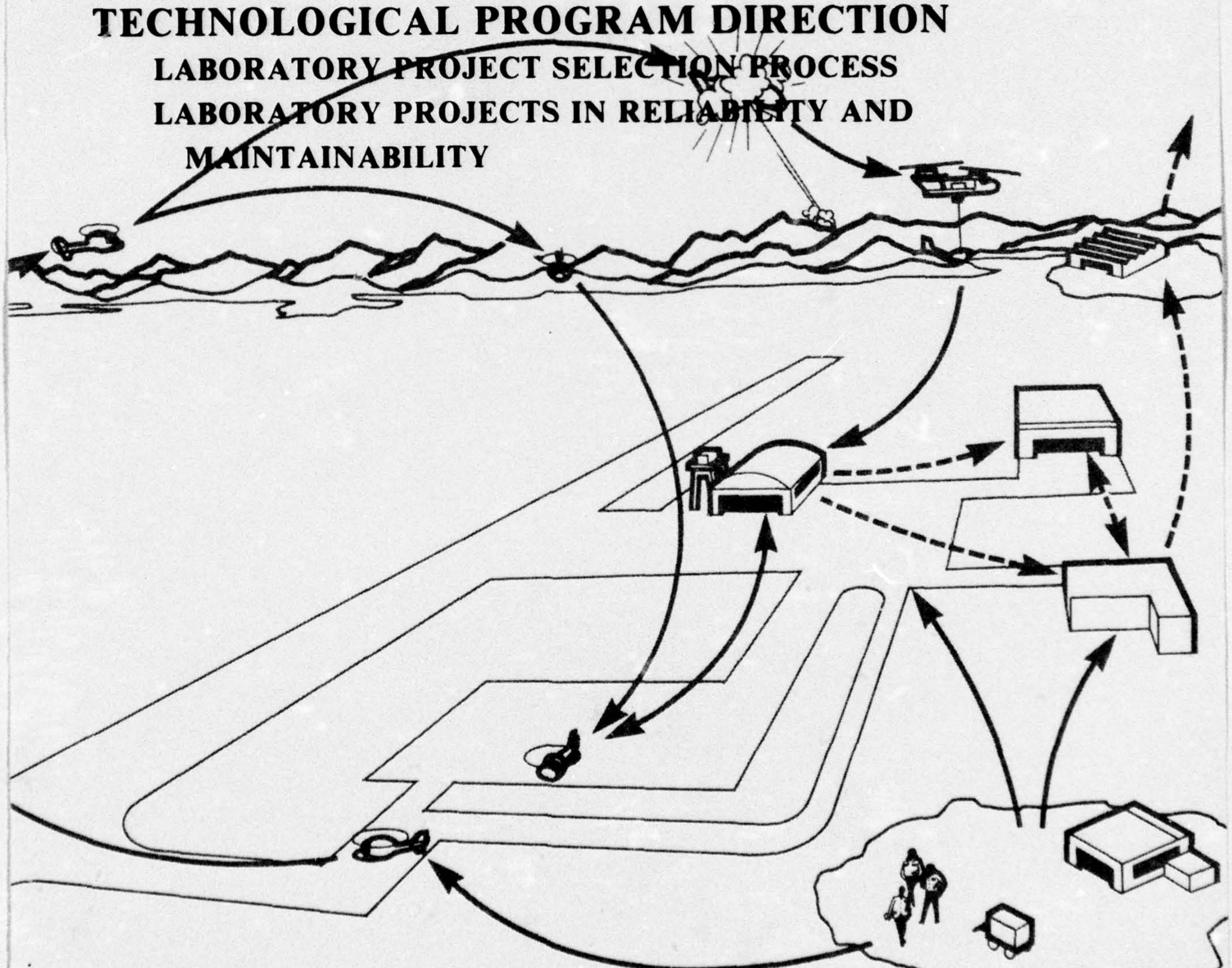


Chart PR–I. Subdiscipline Achievement Goals.



INTRODUCTION

The basic R&D effort in this area is to conduct those exploratory and advanced development programs necessary to define the relationship between R&M quantitative characteristics and system, subsystem, and component design criteria/arrangements and test requirements. Once established, these relationships will allow full consideration of R&M, along with other systems engineering disciplines in the optimization of future Army aircraft. Close working interrelationship is maintained with all other disciplines to ensure that the R&M program is conducted in the most responsive manner possible and to maximize the probabilities of R&M being properly reflected throughout the development of new systems.

Army aircraft have been employed to accomplish a variety of missions and have generally accomplished those missions in an acceptable manner. However, the cost of supporting the aircraft has been extremely high and little effort has been made to reduce the life-cycle cost of any aircraft system. An analysis of current aircraft fleet experience has shown that maintenance and support costs over a 5-year period for the five basic operational helicopter types are about twice those of the original acquisition costs; and financial losses associated with aircraft losses due to noncombat reasons represent about 30 percent of the initial purchase price. Combat losses and worldwide noncombat losses, when compared over a 41-month period, were found to be approximately equal. Further, on an Army-wide basis, aircraft experience an average downtime of 25 percent due to scheduled/unscheduled maintenance and inspections; only a small fraction of this downtime is attributed to a lack of parts. Consequently, the combination of reliability and maintainability problems is taking a severe toll of Army resources.

An R&D program has been developed with the specific objective of providing significantly improved R&M characteristics for future aircraft. The basic program approach is to establish a clear quantitative/qualitative definition of current aircraft R&M characteristics, and to conduct subsequent analyses of design, test, maintenance, quality control, and technology changes that offer an improvement in terms of cost, mission reliability, availability, and other R&M related parameters. Because the R&M program utilizes Army aircraft experience, many of the improvements developed are directly applicable to the current operational fleet. An early major thrust of this program is the development and application of advanced analytical techniques for the quick and accurate quantitative analysis of R&M problem areas and proposed solutions, which are described in more detail subsequently. The short-term objective of the program is to concentrate on the use of current technology, or the development of new technology, to structure R&M design criteria, specifications, and guideline documents applicable to future aircraft systems. This can be accomplished through the use of advanced analytical methods, the development of improved subsystem technology, and the development of improved R&M test methods and procedures. The program described herein advocates the development of R&M technology at the component/subsystem level during the early phases of the program. As criteria/specifications mature, the emphasis shifts from specific component/subsystem R&M investigations to R&M design considerations, testing, and demonstration. Concurrently, as new requirements are developed that extend the capabilities of existing technologies, design concepts, etc., new starts at the component/subsystem level can be initiated as required to continue the improvement of aircraft R&M characteristics.

Four major areas of R&M investigation and research are described in the following subsection:

- Diagnostic and prognostic technology
- Aircraft systems R&M
- R&M modeling and analysis
- Maintenance technology and support

Each area is considered a major subject for problem identification, analysis, and solution. The projected results of R&D efforts planned are presented in the form of trend curves and parameters.

The rational meshing of activites in the several areas of reliability and maintainability R&D to develop complete mission systems is shown on chart RM–I (located at the end of this section). The quantitative improvements in the state-of-the-art in each area expected to be applicable to future missions are also shown.

TECHNOLOGICAL DISCUSSION

DIAGNOSTIC AND PROGNOSTIC TECHNOLOGY

Diagnostic and inspection techniques currently used in Army aviation continue to be inadequate with respect to detection of safety related failure modes, minimizing unnecessary removals, and providing optimum fault isolation. Recent investigations of Army aviation diagnostic system requirements have convincingly demonstrated that achievement of optimum diagnostic capability is highly unlikely if the process outlined in figure RM–1 is not strictly followed.

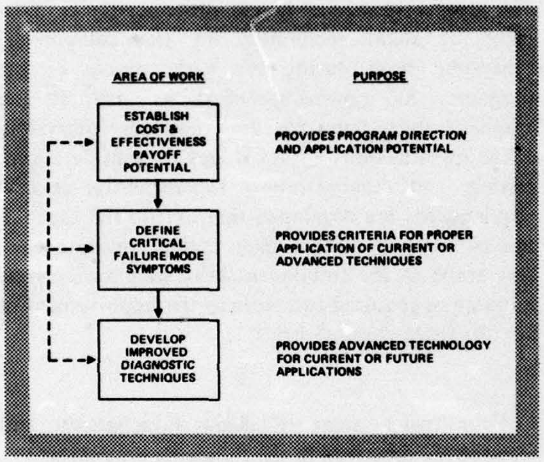


Figure RM–1. Diagnostic/prognostic program flow.

The areas where diagnostic equipment improvements are most likely to provide substantial payoffs include reduced accidents due to material failures, elimination of no defect component removals, reduced supply downtime through prognosis of failures, reduced troubleshooting time and improved mission reliability. The magnitude of today's diagnostics problem is typified by recent statistics which indicate between 20 and 30 percent of all main transmission removals were found to have no failure during depot teardown inspections. Furthermore, it is estimated that approximately one half of all mission aborts are caused by cockpit indications (chip detector lights, oil pressure gauges, etc.) on impending failures with components which are later found to have no defect. The above problems tend to occur for two basic reasons: first, the criteria for the diagnostic technique is inaccurate and/or second, the diagnostic technique failed to perform as required. This condition has led to the basic approach which must be used in achieving an optimum diagnostic/prognostic capability; that is, the failure mode symptoms and critical thresholds must be defined with the development and/or selection of a diagnostic technique.

The laboratory program in prognostic technology is supported by the on-condition maintenance approach, which can be very cost-effective. Specifically, the ability to go on-condition is influenced by the degree to which diagnostic and prognostic detection contributes to the cost of ownership. If the necessary prognostic or condition-monitoring function can be performed without exceeding allowable resource boundaries, the on-condition concept becomes feasible. Emphasis to date has been characterized by investigations of high-frequency resonant techniques for bearings and gears, advanced torque measurement devices utilizing such concepts as magnetostrictive characteristics, and eddy current properties. Other areas of investigation that may enhance aircraft reliability and ease maintenance are application of laser and acoustical holography, neutron radiography, and further work in acoustic emissions.

The advanced technology structures, components, and materials addressed in section ST of the Plan require new diagnostic and inspection capabilities for assuring that reliability is sustained from the viewpoint of both structural integrity and fatigue tolerance. Diagnostics technology provides one the greatest potentials for providing this assurance, while also offering a means for inspecting and repairing components that would otherwise be scrapped because of their unknown condition.

Another aspect of diagnostics is the utilization of sensed and observed signals, parameters, and condition information to logically analyze and fault isolate failures or out-of-tolerance conditions. Cost-effective methods for performing this type of analysis are difficult to identify. One approach is the development of logic analysis techniques that can simplify the repair and maintenance function. For example, a small, portable, suitcase-size logic calculator that assists the maintenance technician in fault isolation and malfunction identification (with or without connection to the hardware) could provide a high level of maintenance diagnostic capability for many components. Such equipment can reduce the skill level and training requirements to maintain advanced technology hardware.

The near term diagnostic technology program has as a major objective the establishment of a clear insight into failure mode symptoms for helicopter gears, bearings and other rotating machinery. Heavy emphasis is being directed toward the investigation of how oil debris can/should be used in assessing the condition of gear box assemblies; this area of work is prompted due to the high rate of unnecessary removals and mission aborts occurring due to inadequate decision criteria currently being experienced through the use of various oil analysis concepts (chip detectors, filter checks, and spectometric analysis). Failure mode progression testing is being used to establish failure onset rates and concurrently assess the capabilities of oil debris or vibration analyses to detect and track the identified modes. Preliminary investigations of diagnostic system configurations are identifying options for establishing how various techniques may be combined into an operational system. Another major area of work involves establishing engine deterioration symptoms which are expected to provide the basis for a gas-path analysis technique. Finally, a number of special diagnostic devices such as fuel flow meters and torque indication systems are under investigation and are expected to provide improved information for field maintenance personnel for assessing general engine performance trends.

The long range diagnostic/prognostic program is directed toward providing effective techniques/concepts for design components such as composite structure and advanced drive systems. These programs will be continuously monitored to determine if specific special purpose diagnostic capabilities are required. Additionally, results of the fault isolation criteria investigations conducted under the Maintenance Technology effort will define any specific device requirement such as ground based maintenance aids for troubleshooting.

AIRCRAFT SYSTEMS R&M

ROTOR GROUP

Studies of the impact of the Army's operational environment on helicopter-rotor-blade failure rates indicate that external causes (combat damage, flying debris, foreign objects, etc.) are considerably greater than causes associated with blade design (fatigue failure, etc.). Maintenance data show that the Army is experiencing very high maintenance support costs primarily due to externally caused damage coupled with extremely poor repairability characteristics. A review of all current operational helicopter classes (utility, attack, etc.) shows that more than 50 percent of main rotor blade removals are due to externally induced damage. Typical damage types are dents, tears, and punctures. Unfortunately, the low inherent field repairability of current blades and the adverse environmental conditions encountered in operational areas limit the number of blades repaired following damage to only 10-15 percent. This low level of repairability is further compounded by the fact that many blades are scrapped following return to a depot maintenance facility because of water entrapment and corrosion incurred during shipment (approximately 40 percent for UH–1 blades). A series of design concept investigations offering a potential life cycle cost reduction has been completed; sectionalized, highly repairable (field plus depot), and expendable concepts were included. Subsequent cost analyses have shown that an expendable blade possessing some degree of field repairability is the optimum arrangement. This occurs because of the combination of production and maintenance cost values related to the high externally induced blade damage rate. Figure RM–2 demonstrates how production and operational costs combine for a typical blade configuration for variations in blade mean time between failure (total failures are a combination of inherent and externally induced failures). Curves of this type can be developed for any blade design arrangement and stated maintenance support concepts; analyses of this type were used in establishing the expendable/repairable design as the concept having the least

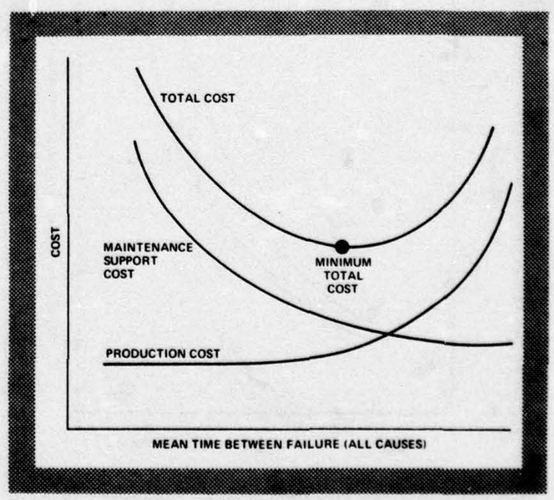


Figure RM–2. Cost relationship for typical rotor blade concept.

expected life cycle cost, and should be further investigated through advanced development effort. Note that increases in MTBF (figure RM–2) above the 1000-hr level generate rapid increases in production cost because of the impact of externally induced resistance that must be built into the blade.

The extremely adverse environment of Southeast Asia has demonstrated that main rotor hubs have been a prime source of Army helicopter service and maintenance problems. Contamination, wear, and malfunctions of the many bearings and their associated close-tolerance sleeves, bearing retainers, oil reservoirs, seals, and shields result in numerous unscheduled inspections, teardowns, and overhauls. Also, frequent servicing adds appreciably to the operating costs and downtime of the helicopter. Elastomeric bearings with their inherent oscillatory motions and no moving parts are being developed to address this problem.

Helicopters are generally plagued with high-level, rotor-induced fuselage vibration which impairs performance, reliability, and maintainability. A current study is documenting the impact of vibration on maintenance, reliability, and life-cycle cost. Analyses indicate that vibration reduction can decrease failure rates by up to 50 percent for certain subsystems. Figure RM–3 is a projection of the relationship between system R&M characteristics and vibration levels measured in the cargo compartment of an Air Force S–3 helicopter. The two points represent actual values; however, the curve has been established using "best judgment." This curve is felt to represent a realistic trend for R&M benefits available through vibration reduction. The trend curve for each subsystem presented in various sections of the R&M volume includes the vibration reduction payoff.

The above items represent short-range programs. Far-term efforts will include investigation of advanced concepts for all rotor system components, with considerable interest directed toward materials and manufacturing. The R&M objectives will generally be satisfied by integrating R&M engineering activities with other disciplines (e.g., performance evaluations of advanced rotor concepts, such as controllable twist rotors, would include extensive analyses and component testing to assure R&M characteristics are properly considered).

Successful development of these new concepts offers advantages in extended component life, higher reliability, improved flight safety, and lower ownership costs. However, the fundamental objective is to reduce life-cycle costs of new mission-oriented rotor systems. Figure RM–4 shows the sought-after reduction in normalized life-cycle cost for the rotor system compared to the UH–1 as a base.

The R&D program plan for improving rotor group reliability and maintainability is coordinated with the structures program, which illustrates the close interrelation of reliability and maintainability with structures technology to ensure that the reliability and maintainability philosophy is properly accounted for

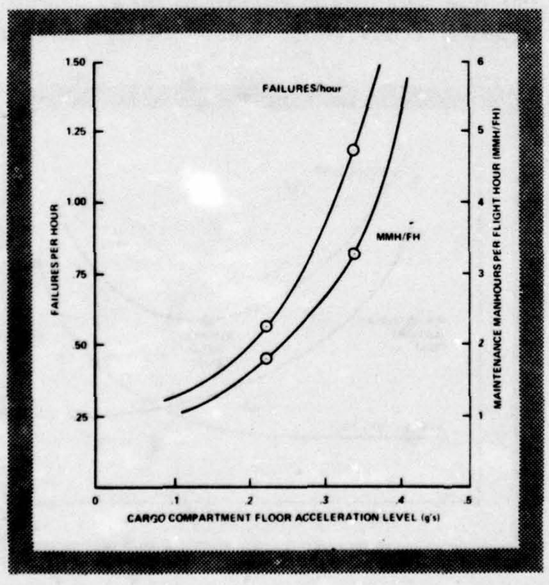


Figure RM–3. Relationship between vibration level and R&M characteristics.

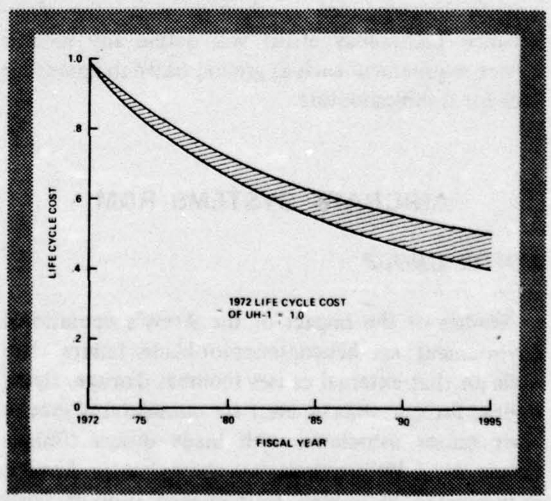


Figure RM–4. Rotor group improvement goal.

in the development of lightweight rotor components. The ultimate objective in all cases is to have completely developed and proven off-the-shelf concepts for engineering design of advanced mission systems.

PROPULSION AND DRIVE TRAIN SYSTEMS

Helicopter transmission system designs have been inherently complex, resulting in numerous fail modes and high fail rates, and forcing low scheduled overhaul (TBO) intervals. Gearbox designs have not permitted field assembly and most failures result in chip contamination of the entire gearbox and subsystems. Shaft clutches, couplings and bearings have short lives and serious failure consequences. Current transmissions have TBOs of about 1200 hr; the mean time between removals averages less than 1000 hr, with some as low as 450 hr. Helicopter powerplants, most of which are gas turbines, have many fail modes and a low mean time between removals. For military aircraft main shaft bearings and oil seals have the highest fail rates. Fuel-system component fail rates are high, often having serious consequences, and are expensive to correct. Combustor and turbine parts are highly susceptible to temperature cycling damage. Almost 30 percent of engine removals to the depot are due to FOD and compressor erosion damage. Erroneous fault diagnosis causes many unnecessary component and engine removals to the depot for repair.

A major effort under this area has been the analysis of design and test requirements necessary to approach effective on-condition maintenance (i.e., the elimination of scheduled overhauls using appropriate inspection criteria to determine when removal is required). Previous research has demonstrated feasibility of the on-condition policy; however, this conclusion was based on analyses of component-level failure trends. It became apparent that part/piece failure trends must be established to properly address component level trends. Figure RM–5 provides the component level along with selected failure mode trends on a Weibull plot. Note that although the assembly level is indicating a constant failure rate (slope of 1.0), some failure modes are indicating an increasing failure rate (slope less than 1.0). If scheduled overhaul times are greatly increased or eliminated, the independent failure mode trends will cause the assembly level failure rate to increase. Such information provides the basis for identifying those part/piece items that must be improved to gain maximum return through implementation of an on-condition maintenance policy.

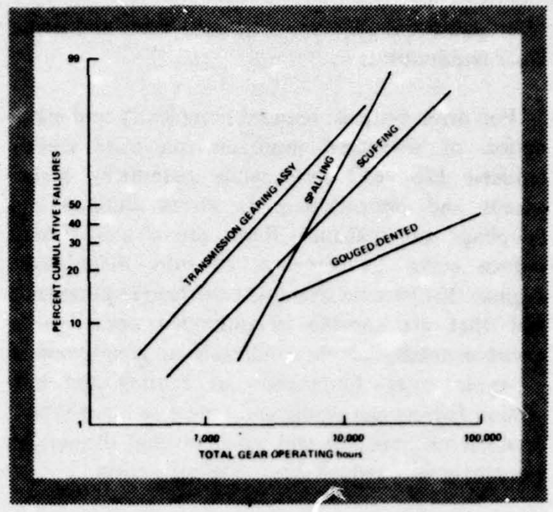


Figure RM–5. Weibull plot of typical transmission gearing assembly and associated fail modes.

For transmission drive systems, in-depth analyses can be performed for new concepts to reduce complexity, define and test new materials, and establish design criteria to eliminate scheduled overhauls. Analyses and tests can be conducted to identify ways to confine metallic failure debris to a small area within a transmission and permit overhaul of gearbox components in lieu of whole assemblies. New concept clutches and shaft couplings can be developed and tested for high-speed applications. For long-range applications, simplified engine-rotor-drive systems can be analyzed and developed. Research and development efforts in helicopter powerplant bearings can encompass extrapolation of contact bearing technology and development testing of noncontact bearing concepts. Simplified fuel systems can be developed, including all electronic scheduling. Simple, efficient environmental debris separators can be developed and tested, along with compressor materials having greater resistance to erosion damage. Advanced hot-section materials and cooling techniques can continue to be investigated and developed to eliminate scheduled overhaul requirements. Development of accurate, simple diagnostic systems can continue to be pursued to eliminate costly, no-defect removals from service. For long-range application, use of less corrosive, more efficient fuels can be investigated. Improved design and development test concepts, coupled with establishment of advanced statistical techniques, can allow the establishment of on-condition maintenance concept for first-fielded items. Development of design arrangements that allow fault isolation to field replaceable modules may

offer significant reductions in parts costs and depot labor requirements.

For drive systems, reduced complexity and elimination of scheduled overhauls can yield greatly reduced life-cycle costs while permitting higher speeds and performance. Improved clutches and couplings can enhance flight safety and further reduce costs. Development of fully modularized engines that have no scheduled overhaul requirements and that are capable of unlimited operation in environmentally hostile conditions can greatly reduce life-cycle costs. Elimination of bearing and hot-section failures can significantly increase flight safety. Modular maintenance and accurate fault diagnostics can also greatly reduce future life-cycle costs.

Sought-after improvement trends in transmission and engine removals in terms of TBO and TBR are shown in figure RM–6. The figure indicates the expectation that by about 1981, the technology will have been developed to a state that will enable the institution of a philosophy for maintenance of powerplants and drive trains based entirely on replacement without provision for overhaul.

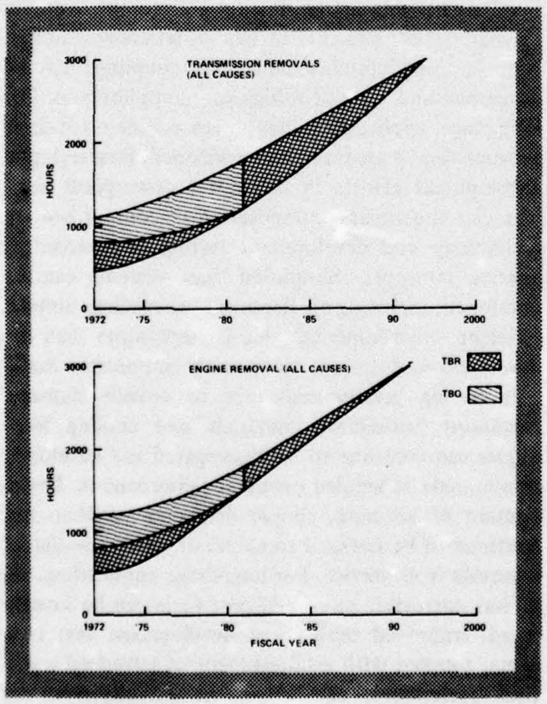


Figure RM–6. Propulsion and drive train improvement goals.

Many of the factors discussed in this area of R&M were also addressed in the presentation of the R&D Plan for Propulsion and Drive Trains. The interface between these two technologies is obvious; therefore, the program plans for both have been coordinated and integrated. This is another prime example of the fact that technological development in one area of the program affects others.

FLIGHT CONTROLS AND UTILITY SUBSYSTEMS

Premature failures of flight control, hydraulic, electrical, fuel, and other utility subsystem components are causing excessive maintenance and logistical burdens, poor mission reliability, accidents, and excessive costs in current inventory aircraft. Avionics subsystems, for example, are sources of frequent failures, and contribute heavily to mission unreliability and subsequent maintenance action. Reasons for these failures vary, depending on the component, but include inadequate design criteria, test requirements and procedures, poor maintenance procedures and practices, inadequate quality assurance provisions, and lagging technology. Many of these deficiencies exist, in addition, because of past policies and procedures under which off-the-shelf helicopters, certified to FAA specifications, were procured and applied to Army training, utility, and combat missions.

To improve the reliability and maintainability, as well as aircraft availability and cost-effectiveness of future Army aircraft, a research and development program is currently being considered that will identify the major deficiencies existing on inventoried aircraft and determine the basic causes of deficiencies. The basis for deficiencies will be determined by selecting representative components as subjects for detailed investigations into development and use. This approach will allow determination of inadequacies in design or test requirements, improper maintenance procedures or practices, inadequate quality assurance provisions, or lagging technology. Results of various investigations will generate a sound basis for revised specifications, standards, practices, and procedures; allow stipulation of more precise requirements for future generation aircraft; and can result in immediate product improvement applications. In addition, as lagging technology is detected in certain areas, R&D efforts will be initiated to advance the state-of-the-art. Typical efforts currently underway include detailed quantitative/qualitative R&M analyses of

mechanical flight control elements (cables, rod end, etc.), hydraulic actuators, electrical system components, stability augmentation systems, and fuel system components.

In conjunction with the major R&M thrust, a continual cognizance will be maintained of other advancements in technology. Efforts can be initiated to conduct R&M assessments during these development programs and to participate from an R&M standpoint, in these ongoing projects – the objective being to enhance R&M features along with performance, weight, and cost considerations. Sought-after improvement trends in flight control and utility subsystem reliability and maintenance burden are shown in figure RM–7. Statistical data regarding these subsystems are somewhat limited but indicate that the distribution of repair times is rather dense and support the continuous relationship between reduced failures and reduced maintenance depicted in figure RM–7.

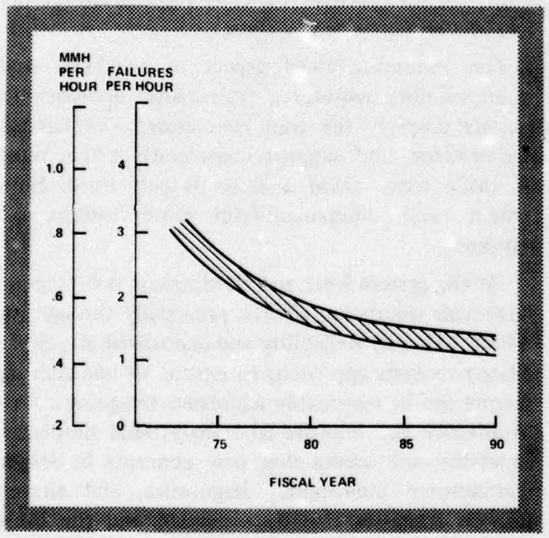


Figure RM–7. Flight controls and utilities systems improvement goals.

The R&D approach to reliability and maintainability can result in:

- Accurate and definitive design and test criteria.
- Accurate and specific design and test requirements.
- Detailed maintenance manuals.
- Simpler maintenance procedures.
- Fewer maintenance actions.
- Improved or advanced technology to enhance R&M.
- Accurate definition of the Army aviation operational environment.
- A thorough basis for evaluating contractor proposals.
- Improved program management techniques.
- Product improvement potential in areas of detailed investigation.

In more general terms, specific information will be made available for application to the improvement of reliability and maintainability of future Army aircraft systems and the second generation of these systems.

The ultimate R&D objective is to have completely developed and proven off-the-shelf engineering design of advanced mission systems. See the Aircraft Subsystems section (AS) for additional discussion of reliability aspects of these systems. The R&M plan is completely integrated with R&D efforts described in that section.

STRUCTURES AND AIRFRAME

Statistical analyses of operational R&M data have shown that approximately 25 percent of all helicopter unscheduled maintenance effort is expended on the airframe (primary and secondary structures). This statistic is virtually constant regardless of helicopter class (utility, observation, transport, etc.). Airframe maintenance is the driving requirement for major aircraft overhauls (3000 hr overhaul cycle for UH–1) and this overhaul is dominated by structural repair, including a 90 percent transparent structures replacement rate. Skin cracks, defective fasteners, failed door hardware, rivet replacement, windshield deterioration and access panel failures are typical failures experienced. Additionally, the correction of combat damage involves considerable man-hours because of the complexity associated with sheet metal rework. Considerable improvements are required in airframe R&M characteristics for future systems.

The current R&D program in R&M for attacking the above situation is structured to include both short- and long-range efforts. Efforts are being directed toward obtaining a better understanding of

secondary structures and windshield problems and determining potential changes required in specifications and concepts necessary to provide immediate fabrication, lab testing, and operational evaluation of specific design concepts; these efforts can provide the basis for recommended approaches applicable to aircraft systems in the 1975-1980 timeframe. Reliability and maintainability evaluations of advanced structures concepts will be a main R&D thrust in the upcoming years. During FY76-77, a thorough operational evaluation (with emphasis on R&M) will be conducted for an all-composite aircraft (fiberglass). This problem will include static and fatigue testing, environmental effects, evaluations, and maintenance characteristics assessments. Results will be used to establish specific R&M design requirements for this type of structure for application to future systems. Long-range R&M evaluations of structures should include consideration of various other composite materials and fabrication concepts. Specific effort can be directed toward maintenance concepts for integrated and parasitic armor design arrangements. Selected fasteners and bonding concepts potentially usable for field maintenance can also be subjected to detailed laboratory and operational evaluations.

The above efforts, coupled with the significant reduction of maintenance burden envisioned as a result of rotor vibration isolation, have a high payoff potential in terms of increased aircraft availability and decreased number of skills of maintenance personnel. It is expected that the production version of UTTAS will benefit directly from the secondary structures and windshield efforts. The curve in figure RM–8 is considered conservative in predicting the trend for MMH/FH decrease for the period in question (based on utility-size vehicles). Figure RM–8 was developed independent of cost. It is highly unlikely, however, that the reduction in maintenance burden can be achieved without some increase in aircraft initial cost. Consequently, the structures and airframe R&M program will require continuous cost analyses to ensure that the maintenance burden decreases are not offset by increased initial cost. It is expected that as the program develops, and suitable cost data are available, figure RM–8 will be replaced with a combined cost and maintenance burden objective trends.

Again, the R&M and the structures and materials R&D plan have been coordinated and integrated to provide for the essential interchange of technological knowledge and developments.

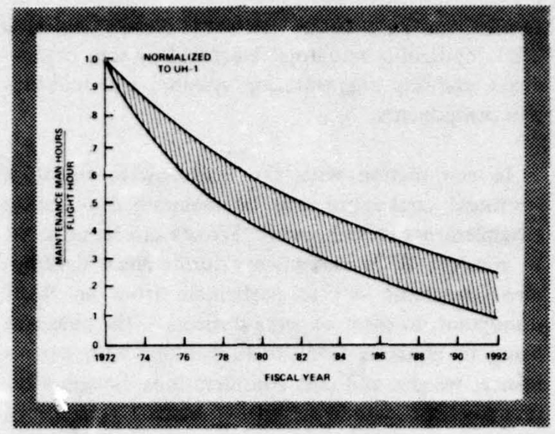


Figure RM–8. Structure/airframe improvement goals.

MODELING AND ANALYSIS

As operational Army aircraft increase in sophistication, the estimation of their reliability, maintainability, required support, and operational capabilities also becomes increasingly complex.

The multi-disciplined aspect of reliability and maintainability requires a system-level approach to address properly the combined design, operational, maintenance, and support considerations that must be made when R&M analysis is performed. Both system- and component-level considerations are required.

At the system level, special attention is devoted to large-scale simulation efforts, principally through the ARMS (Aircraft Reliability and Maintainability Simulation) analysis approach, to ensure all contributing factors can be reasonably addressed. On-going efforts to advance and improve laboratory R&M simulation capability will assure that new concepts in design, maintenance philosophy, diagnostics, and aircraft mission scenarios can be evaluated and the R&M implications to design identified. Figure RM–9 portrays the simulation process that is addressed. The ARMS analysis provides the tools that enable the laboratory to assess the impact and interaction of reliability, maintainability, safety, vulnerability, and survivability parameters on the tactical performance, mission success, availability, resources, and operational costs of current and future (conceptual) Army aircraft.

At the component level, detailed analysis of R&M parameters can be directly addressed as they relate directly to designed hardware function and performance. An understanding is required of specific

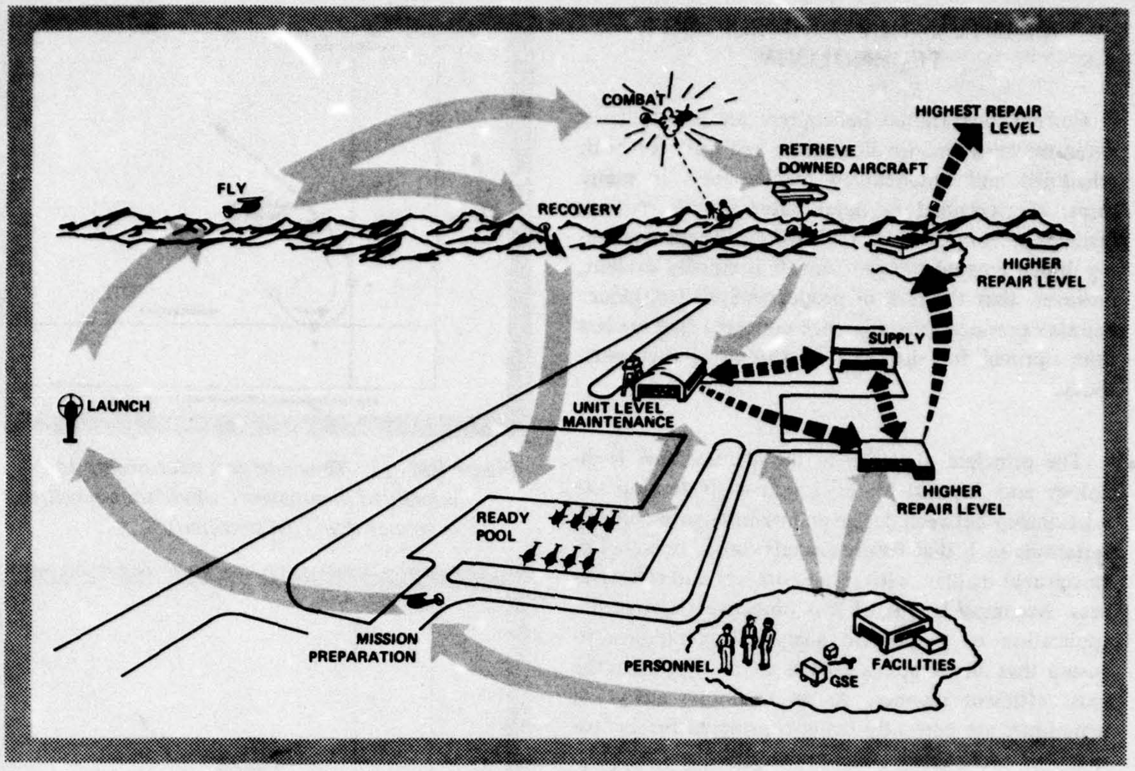


Figure RM–9. ARMS model.

failure modes, functional and physical characteristics, and those factors that cause malfunctions and failures. Also, the resource expenditures and costs associated with designs that meet R&M specifications heavily impact the philosophy of design for maintenance. Presently, emphasis is placed on design for on-condition maintenance. Investigations have shown that many components can be designed for on-condition, which can eliminate the need for a TBO (time between overhaul). Certain fundamental considerations dictate if and when a TBO should exist. Figure RM–10 shows how cost factors (time or dollars) vary with the unscheduled/scheduled maintenance ratio, and the TBO (scheduled overhaul) point as measured in standard deviations from component average design life. Elimination of catastrophic failure modes and the use of cost-effective condition-monitoring can eliminate an established TBO (essentially, the TBO is extended to such a large value that it does not exist for all practical purposes). Simulation and analytics can provide insight into the many facets of R&M technology that require attention for defining and evaluating tradeoffs that must be made in the design process.

Further research is required to develop new techniques in the areas of R&M testing, maintenance logic analysis, and R&M analysis of the impact that advanced structures components will have on the ability to operate, maintain, and diagnose the condition of future aircraft.

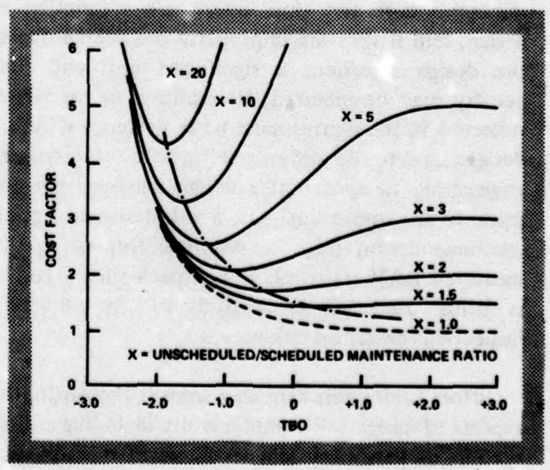


Figure RM–10. Cost factor influence on TBO selection.

MAINTENANCE AND SUPPORT TECHNOLOGY

Current operational helicopters are experiencing extensive maintenance downtime and cost for both scheduled and unscheduled maintenance. In many cases, as explained in detail later in this section, inadequate consideration of R&M characteristics during design created the problem. It is equally evident, however, that the lack of proper analysis techniques has also produced maintenance concepts that are less than optimal for the aircraft systems as they exist today.

The principal objective in the Maintenance Technology and Support Materiel area is to develop the relationship between design and maintenance concept variations such that future aircraft can be operated in an optimal manner with respect to cost and effectiveness. Accomplishment of this objective requires the application of responsive analytical techniques to ensure that all research activities are conducted in the most efficient manner. As an example, analytical techniques are currently being considered for evaluation of scheduled maintenance concepts. Figures RM–11 and RM–12 indicate variations often found in scheduled maintenance intervals and total cost and total maintenance man-hours (scheduled plus unscheduled) for a given design. Curves of this type can be generated for any component where the cost or time to renew the component before failure is less than that after failure has occurred. Once developed, these curves can be used in establishing the intervals and amount of scheduled maintenance that should be applied. The boundaries created by the minimum cost and time points are a function of design, and if they are improperly considered during the design selection, a significant cost and time penalty may be incurred. Recognition of the trends reflected in the figures must be in evidence if future designs are to be optimized from a total systems engineering viewpoint. If a design has been selected prior to the above analyses, a maintenance support recommendation may be obtained through use of measured R&M statistics; an approach similar to this is being used in the analysis of the scheduled inspections described below.

Effort under this area also stresses the qualitative aspects of design for maintainability including consideration of personnel skill levels, support equipment interfaces, and application of diagnostic/prognostic concepts. Results from the qualitative analyses can be

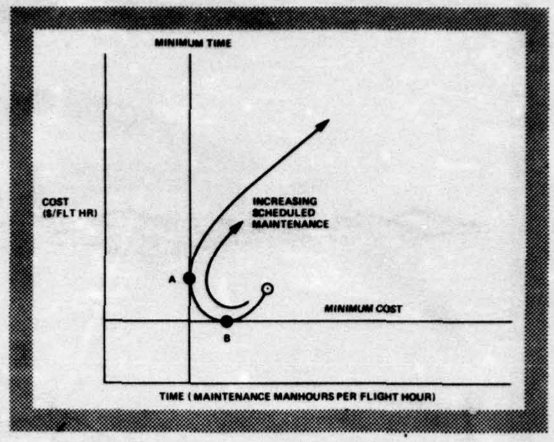


Figure RM–11. Time and cost relationship to scheduled maintenance where time sensitivity is greater than cost sensitivity.

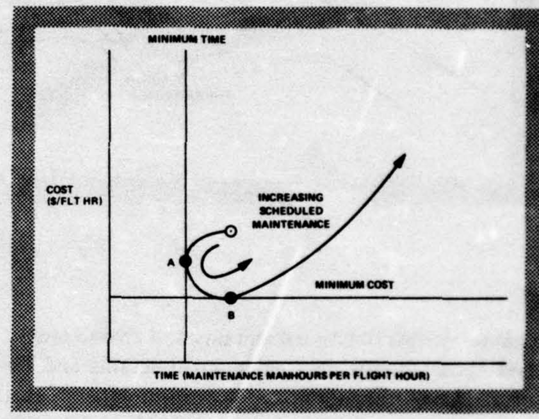


Figure RM–12. Time and cost relationship to scheduled maintenance where cost sensitivity is greater than time sensitivity.

combined with quantitative data such as described in paragraph 1 to provide a total responsive effort under the broad area of Maintenance Technology and Support Materiel. Application of program results will be achieved through proposed improvements to existing specifications and standards and the development of design guides. Satisfaction will be achieved through an aggressive R/D program.

The current short-range aviation R&D program in maintenance technology is addressing scheduled maintenance (inspections) and major component maintenance design considerations. These two areas have been singled out as providing the high payoff potential in reduced aircraft downtime. These investigations include design studies, to be followed by

laboratory evaluations of certain design concepts that appear to offer improved maintenance characteristics. Finally, the short range maintenance technology program will pursue the definition of fault isolation criteria. This effort is prompted by the reported frequent occurrence of "shotgun" maintenance in correcting certain system level problems such as vibration. This program will identify special purpose equipment (such as diagnostic aids) or design considerations which are required to minimize the fault isolation problem.

It is expected that the maintenance technology program will have as its main objective the continuing support of all advanced development projects within the total R&D program. Typically, during the Advanced Technology Engine (1500-hp demonstrator) program, certain maintenance design investigations were conducted that led directly to the adaptation of significantly improved maintenance design concepts for the UTTAS engine currently under development. The Advanced Technology Engine (ATE) maintenance investigation included information maintenance demonstrations and evaluation of logistical support considerations. Efforts of this type during the advanced development period are normally expected to provide the greatest payoff per dollar than at any other period in the development of technology. Currently underway are maintenance investigations of the elastic pitch-beam tail rotors, elastomeric bearings for main rotor application, roller-gear-transmission concept, field-replaceable rotor blade pockets, and field-repairable rotor blades. These programs (along with efforts to develop new concepts in instrumentation and design that will allow for improved diagnostic and prognostic capabilities) typify the type of effort that is required to achieve improvements in maintenance technology. In this manner, maintenance technology will help improve the R&M characteristics of design. Efforts in this area are in conjunction with the Ground Support Equipment (section MS) of the plan under the heading of Test and Diagnostic Equipment.

The payoff of R&D efforts in maintenance technology, coupled with improvements in reliability, is expected to take two forms. The first will be a significant reduction in total maintenance downtime that will be reflected in increased aircraft availability and reduction in total maintenance personnel requirements. The second will be a decrease in maintenance-induced aircraft accidents through the simplification of maintenance tasks. Figure RM–13 shows the sought-after improvement trend in reduced maintenance downtime over the time period covered by this document. The curve is considered applicable to a utility-sized vehicle, but is representative of that expected with all types of Army helicopters. The starting value of downtime used in figure RM–13 is based on operational data extracted from DA Form 1352s for the UH–1H helicopter. This value includes certain supply and administrative downtimes that are not necessarily related to the design; however, the trend for maintenance reduction is considered valid and may be used to reflect projections for any desired definition of downtime (inherent, achieved, or operational).

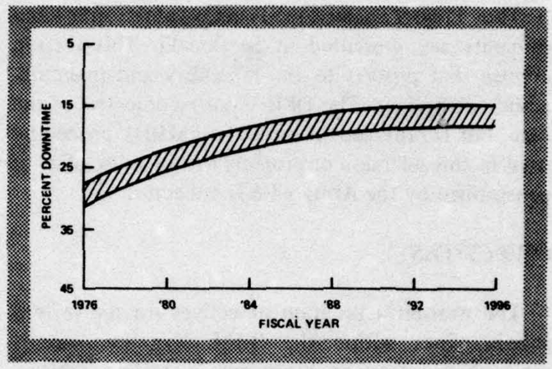


Figure RM–13. Maintenance technology improvement goal.

Advanced techniques and methods for aircraft condition-monitoring have recently been developed by AVSCOM. This unique application of relatively simple inspection procedures is titled, "Aircraft Condition Profile." Briefly stated, the method consists of selecting basic airframe "indicators," such as loose and missing rivets, structural alignment, corrosion, etc., and assigning coded symbols that represent the indicated condition and gradations between good and poor. The coded information is readily translatable to computer programming or may be visually interpreted to yield a rapid and accurate assessment of the aircraft condition. It has proved to be a highly efficient maintenance monitoring system and a powerful management tool. It can be used to establish thresholds of airworthiness and serviceability as well as providing criteria for selection of aircraft for cyclic depot maintenance. It has marked the end of an era in which the traditional criteria of accumulated flying hours and chronological time in service were the sole criteria, regardless of the aircraft's actual condition. As more data is accumulated and more experience is gained with the aircraft condition

profile, the potential for its contribution toward RDT&E efforts in the reliability and maintainability field will be magnified.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the reliability and maintainability disciplines. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in this selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the R&M discipline can be established from the near-term quantified achievement goals listed in chart RM–1. It is important to note that the R&M technology is oriented towards better utilization of resources as opposed to primarily advancing the performance of designed hardware and as such, identifies the tradeoffs and areas of compatibility between resources and performance. The R&M technology establishes a system of checks and balances in the design process which is reflected in the following R&M objectives.

- Establish diagnostic and prognostic concepts to improve V/STOL R&M characteristics.
- Develop advanced R&M component design concepts which contribute to achievement of 25% reduction in support costs and a 30% reduction in maintenance downtime.
- Establish R&M analysis techniques for new systems. Develop criteria and concepts to achieve 25% reduction in maintenance support costs. Develop concepts for 30% reduction in maintenance downtime.
- Establish testing methodology for R&M which will contribute to achievement of 25% reduction in support costs and 30% reduction in maintenance downtime.

PROGRAM PRIORITIES

General. Table RM–A presents, in a prioritized listing, the R&M technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. R&M technology subdisciplines are represented by the following major topical areas:

- *Diagnostics and Prognostics.* This pertains to the ability to determine the condition and to predict condition progression of components through the use of instrumentation and/or indicating devices for purposes of enhancing reliability and maintainability characteristics. This includes sensors or pick-ups, signal processing equipment, logic circuiting, indicating devices, and those devices and techniques which allow the functional hardware such as engine, transmission, rotor blades, etc., to be monitored for maintenance, replacement or overhaul determination.

- *Modeling and Analysis.* As related to R&M, modeling and analysis considers the mathematical functions, statistical relationships, and algorithms of both deterministic and simulation type which provide the technical understanding of design maintainability and reliability properties, and relates these design characteristics to other factors of operation, maintenance and support which have a bearing on the design process. Also included in this subdiscipline is R&M testing methodology which addresses the issue of measuring and tracking R&M parameters which are often complex functions of thermal, physical, electrical, and mechanical properties coupled with conceptual properties of maintenance, logistics, and operations. The ability to accurately assess and understand factors as pertain to direct operating costs effectiveness of military aircraft missions, etc., is closely related to knowing not only what the R&M effects are on aircraft but also on determining how to measure, test, and assess what the reliability and maintainability characteristics are for helicopter systems. Just as it is important to have wind tunnel test procedures

to measure aerodynamic properties, it is necessary to develop test methodology for measuring R&M parameters in an efficient manner.

- *Aircraft Systems R&M.* This area pertains to the inclusion of R&M philosophy in the design concepts of components with attention focused on those designs which will provide for improved reliability in the component design function and/or provide for ease of maintenance in a cost effective manner through reduction of maintenance time, special tools, etc. Component level improvements yield visible and measurable results and offer improvements which the user can see and understand. System level improvements in R&M are often unmeasurable and less detectable than improvements in component design.

- *Maintenance and Support Technology.* The methodology is addressed in this area which allows the design objectives for performance, reliability, and maintainability to be met and sustained through proper integration of the design philosophy with the maintenance and support philosophy and concepts. The goal is to develop the relationship between the functional hardware design and the maintenance concept and theories in such a way as to allow future aircraft to operate in a highly cost effective and reliable manner.

Vehicle Subsystems. Vehicle subsystems, as related to R&M technology, are categorized as follows:

- Rotor group
- Propulsion and drive
- Flight control
- Aircraft subsystems
- Airframe/structures
- Weapons support systems
- Avionics

These subsystems essentially cover the entire aircraft and is consistent with the scope of consideration that must exist when addressing R&M technology.

System Effectiveness. In the area of systems effectiveness, the fundamental influence of R&M technology is reflected in the resources required to operate and maintain the designed hardware. Therefore, life-cycle costs are greatly affected. Mission reliability and the availability of aircraft to perform the mission is a direct product of the level of R&M technology applied. The total maintenance burden when considered in light of the mission that the aircraft must perform, bears a one-to-one relation with the maintainability aspects of the design.

Priorities. With reference to table RM–A, the R&M subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

TABLE RM–A
PRIORITIZED R&M OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Diagnostics and prognostics	I	• Rotor group	I	• Life cycle costs	I
• Aircraft systems R&M	II	• Propulsion and drive	II	• Reliability	II
• Maintenance and support technology	III	• Flight control	III	• Maintenance burden	III
• Modeling and analysis	IV	• Aircraft subsystems	IV	• Availability	IV
		• Airframe/structure	V		
		• Weapons support systems	VI		
		• Avionics	VII		

MAJOR THRUSTS/RATIONALE

General. The major thrusts in R&M technology for helicopter or V/STOL aircraft are analogous with the near-term objectives stated above. These thrusts reflect how best the R&M posture of Army airmobility can be improved when considering collectively that which has been accomplished to date, and what remains to be accomplished in the years immediately ahead. Collectively, it is the development of diagnostic/condition monitoring capability, advanced R&M component design concepts, system level R&M analysis capability, and improved testing methodology for R&M for air vehicle subsystems to reduce life cycle costs and improve reliability-maintainability-availability.

Development of Diagnostic/Condition Monitoring Capability – Priority I. There are several alternative methods available for improving overall aircraft R&M characteristics. These include inherent design properties, aircraft support concepts, and improved diagnostic sensoring and condition monitoring. The latter provides one of the most feasible methods for improving aircraft R&M, while creating little or no impact on current design methods and performance characteristics as opposed to alternative methods of improving R&M. Also, the cost of such an approach is relatively independent of costs associated with the development of functional aircraft components which are monitored, since independence between function for performance and function for diagnosis can be maintained. Present state-of-the-art is capable of providing improved diagnostic/sensoring capability on a cost effective basis. It is the application of this capability to improve Army aircraft R&M that is presently lacking. The current AIDAPS program represents only one approach to an improved diagnostic/sensoring capability. Laboratory developed concepts will be applicable not only to future designs but also be the current fleet.

Aircraft Systems R&M – Priority II. Although many system factors contribute to determining the value of R&M characteristics exhibited by Army aircraft, the primary factor with the most influence and sensitivity is the actual component design. Extensive investigations to date in the R&M program to define areas for improved design as in transmissions modularization, vibration effects on component lives, on-condition maintenance requirements, and elastomeric design criteria points out the potential that exists for greatly improved component R&M properties. Logistics concepts, maintenance plans, and repair and overhaul procedures are all after-the-fact contributors to improving R&M compared to the design itself. The high dollar cost of aircraft components coupled with the high risk and cost of secondary effects of component failures provides the necessary incentive to continuously improve component design R&M. Illustrative of the impact of secondary failure effects is how a small component such as a door latch can cause total loss of a multimillion dollar aircraft. On a cost basis alone it is very effective to incorporate R&M considerations at the component level. Redesign of current fleet components is not always practical; therefore, advanced component R&M design should be directed primarily at future aircraft.

Modeling and Analysis – Priority III. The need for advanced R&M analysis grows with the complexity of the logical alternatives for designing and maintaining advanced systems. The interdependencies and operational influence of one subsystem with respect to another become lost unless the relationships in mathematical models and equations are sophisticated enough to properly explain the total phenomenon. To illustrate, the laboratory does not at the present have satisfactory analytical tools developed to treat the system level influence of sophisticated diagnostic and sensoring capability as addressed in Priority I. The structuring and treatment of this problem must be included in simulation and deterministic R&M analysis such as ARMS to provide analytic visibility.

Maintenance and Support Technology – Priority IV. One of the major causes for R&M design criteria not being closely achieved or reflected in production aircraft is the lack of testing methodology which would allow for deeper understanding of how R&M specification and requirements can be measured and demonstrated in a practical and cost effective manner. Coupled with an improved methodology for testing and measuring would come on improved knowledge of how to correctly specify and relate R&M parameters to other design characteristics. The Laboratory has expended a considerable amount of resources to develop design criteria for several helicopter subsystems, and the program should now be augmented by a concentrated effort to develop the testing methodology to assure that the R&M design criteria developed can be effectively measured and related to other system parameters through proper testing techniques and analyses.

LABORATORY PROJECTS IN R&M

INTRODUCTION

The research program in reliability and maintainability technology is addressed at the (6.2) exploratory development and (6.3) advanced development levels. The objective is to develop advanced technology and equipment with improved military operational capabilities for Army aircraft through improved reliability and maintainability characteristics.

Research in this area is conducted by the Eustis Directorate at Fort Eustis, Virginia, and the Lewis Directorate located at the NASA-Lewis Research Center, Cleveland, Ohio.

The Eustis Directorate programs constitute the major portion of the R&M effort, which includes both 6.2 and 6.3 work, and encompasses all subdisciplines addressed in the program.

The Lewis Directorate program is in the area of propulsion and, as such, focuses on gas turbine R&M characteristics.

DESCRIPTION OF PROJECTS

Reliability and Maintainability Technology. Project 1F262209AH76-TA IV is an exploratory development effort to develop advanced technology and equipment to provide advanced military operational capabilities of Army aircraft in a cost-effective and timely manner through improved reliability and maintainability characteristics. Specific requirements for current and near-future aircraft are given primary consideration, together with full support of project-managed programs such as UTTAS and AAH. Major goals supported reflect improved durability, reliability, maintainability, and mission effectiveness. The identification of R&M issues associated with current fleet aircraft is ongoing. Design analysis is performed and new concepts are assessed. R&M analyses consider the joint effects of design, operation, and maintenance.

Previous efforts have concentrated on determining the causes for R&M deficiencies in currently inventoried helicopters and conducting concept investigations to improve system- and component-level R&M characteristics. It has been determined that the design, test, and acceptance criteria are not sufficient to meet R&M requirements. Also, major factors causing component removals are often external to design, but must nonetheless be addressed. The influence of rotor-induced vibration on component failures has been quantified and judged a significant burden on the maintenance posture.

Investigations and testing of blade segments for sectionalized and highly repairable rotor blades have been addressed. Tests on bearingless fiberglass tail rotors have been performed. Effort has been initiated and is continuing to develop detailed design criteria for elastomeric bearings, which offer big payoff in terms of R&M. The on-condition maintenance concept has been investigated, with results indicating that the application should be pursued where technology and economics allows. In-house tests of high-speed oil seal concepts have been promising, and abradable and rub-tolerant gas path seal materials have been evaluated that will result in a seal material that is more rub tolerant. Exploratory development design has been done in the areas of tapered roller bearings, engine erosion protection, and a fabricated transmission housing. Investigation to identify and recommend corrective revisions to deficient documentation for helicopter flight control and utility systems has been addressed. Preliminary design and qualification criteria for secondary structures and transparent enclosures has been established and concepts for super-hard canopy coatings have been developed. In-flight vibration surveys are completed on UH–1, CH–54B, OH–58A, and CH–47C aircraft to correlate failures with vibration parameters. Hydraulic hose chaffing tests are completed. The probabilistic R&M simulation effort has been well established as a useful analysis tool. Investigation of acoustic signal analysis as a diagnostic tool has been addressed, as have several advanced sensor concepts that offer promise of improving the condition-monitoring capability. Oil debris monitoring also is progressively addressed and fatigue crack detection devices have been prototyped. All of these efforts are directed toward improving the reliability, maintainability, and diagnostic posture of Army aircraft through advanced technology.

Reliability and Maintainability. Project 1F263209DB38 is an advanced development effort to provide comprehensive component and system reliability and maintainability credibility by validating improved R&M designs, test and acceptance criteria and establishing confidence in advanced concepts developed under 6.2 efforts. Successful results of this work will provide significant and timely improvements in Army aircraft operational R&M characteristics. Emphasis will be directed towards development

of diagnostic/condition-monitoring capability, advanced R&M component design concepts, system-level R&M analysis capability, and improved testing methodology for R&M for air vehicle subsystems to reduce life cycle costs and improve reliability, maintainability, and availability.

Programs have been initiated to design, fabricate, and test hardware components and thereby provide comprehensive R&M data, establish service and functional suitability, and demonstrate new methodology for imposing R&M as an issue in designing secondary structures. The concept of a bonded, field-replaceable, rotor blade pocket has been successfully flight tested, and field service evaluation is about to be initiated. Ground testing of both the rotor isolation system and the replaceable rotor blades has been initiated.

All efforts under this project will continue to emphasize thorough R&M assessment of advanced development projects such that subsequent engineering development programs will properly reflect R&M considerations. Maximum use of operational suitability (field) testing is used to gain the most responsive insight.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the R&M R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 and 6.3 R&M R&D efforts are shown in table RM–B. Included in the table is the ratio of the R&M efforts to the total 6.2 and 6.3 R&D AMRDL efforts.

TABLE RM–B
TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.2*	1F262209AH76-TA IV	1535	10%
6.3**	1F263209DB38	516	4%

***Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.**

****Based on Command Schedule dated 16 April 1976**

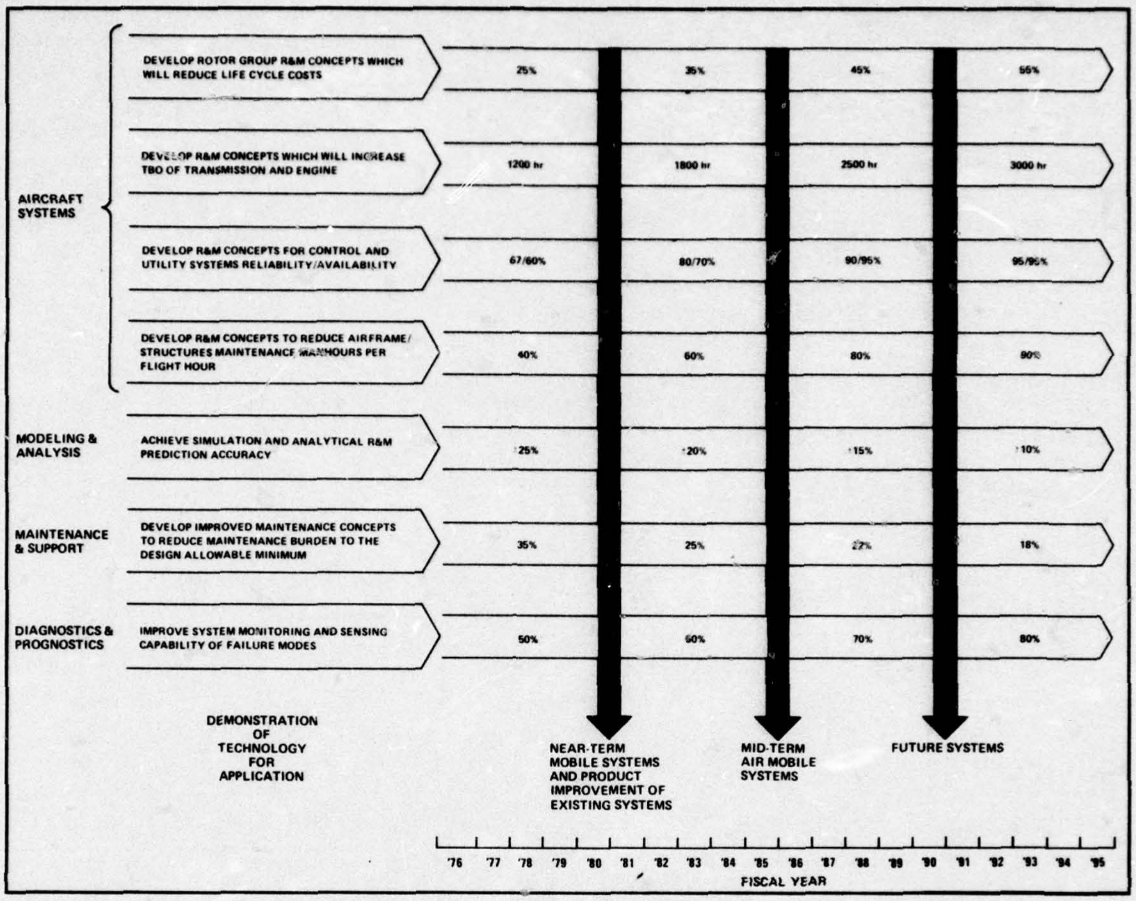


Chart RM-I. R&M Achievement Goals

INTRODUCTION

Aircraft safety and survivability is described as the development and application of those techniques and concepts that allow aircraft systems and subsystems to withstand or to continue required functions when exposed to adverse outside elements. These outside elements include the enemy, nature and, in some cases, the crew itself in the form of misjudgment.

The ability of an aircraft and crew to survive in combat with reasonable assurance of completing the assigned mission is known as survivability. R&D activities under this broad classification include threat analysis, reduction of detection, and ballistic protection of aircrew and aircraft. The survivability element is heavily influenced by the threat environment associated with the mission and is complemented by the design of the aircraft subsystems and significant features such as size, agility, and onboard armament. Threat analysis involves intelligence sources, synthesis to determine critical weapon characteristics, and assessment of weapons effects; the results of this analysis allow the development of potential countermeasures and effectiveness assessment. As the threat level increases, the relative effectiveness of reduction of detection, ballistic protection, and tactics changes rather significantly (figure SS–1). As the level increases, tactics plays an increasing role in providing the requisite assurance of survivability.

Safety pertains to the ability of an aircraft and its crew to survive in a noncombat environment. In this regard, safety is somewhat redundant since the need for crashworthiness and fire prevention is implicit in the need to survive combat damage. Safety R&D efforts have been divided into these basic elements: in-flight (operational) safety, in-flight and postcrash fire prevention, and structural crashworthiness.

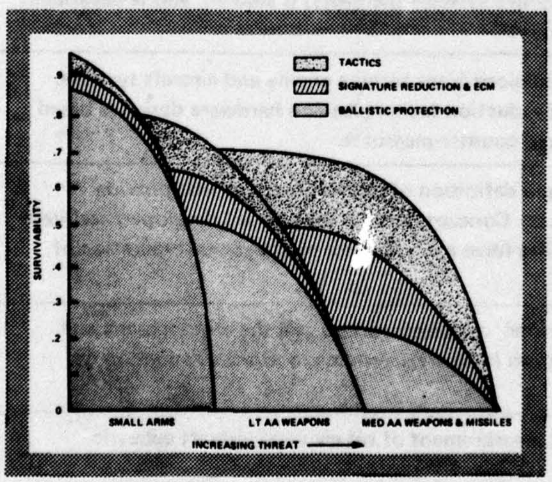


Figure SS–1. Changes in survivability methods with increasing threat.

Research and development in safety and survivability is, to a great extent, applicable to all of the Army's planned airmobile missions. The emphasis on safety and survivability depends on the mission. AAH and AAWS, for example, have greater emphasis on combat survivability than do cargo-carrying aircraft because of their combat roles. Safety and survivability improvements incorporated as an integral part of a new mission system must be considered in the initial stages of engineering design to achieve the most effective design for the least cost and performance penalty.

Within each safety and survivability subarea, quantified achievement estimates have been established as presented in chart SS–1 (located at the end of this section). Incremental achievement goals are shown for the 20-year span covered by the Plan.

The subdiscipline areas of safety and survivability discussed in this section are:

- Survivability through reduced detectability
- Survivability through aircraft and aircrew protection
- Safety
- Aircraft Survivability Equipment (ASE)

TECHNOLOGICAL DISCUSSION

SURVIVABILITY THROUGH REDUCED DETECTABILITY

GENERAL

The major thrust in reducing aircraft detection (which is a form of passive countermeasure) is to formulate concepts and develop means to provide an aircraft with an inherent low detectability signature. This approach degrades or denies target acquisition by enemy weapon systems that use the aircraft signature characteristics for surveillance or guidance. Aircraft may be identified and acquired as targets by

techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing.

Countermeasures against threat systems can involve either reduction of the aircraft signature, deception (where the sensors are confused by jamming or decoys), or using an efficient combination of both signature reduction (passive countermeasures) and deception (active countermeasures). Ideally, passive countermeasures are designed into the aircraft at minimum penalty. However, when the threat is postulated for a specific mission or the performance degradation is significant, these countermeasures can be made available as kits, to be used only when required. Signature reduction, which is normally broadband, is effective against a variety of weapons. Active countermeasures are generally more sophisticated and dependent on the precise characteristics of a specific guidance system or sensor. They are likely to appear as mission-oriented kits complementing passive systems on the aircraft and must incorporate flexibility to be capable of defeating the variety of sensor modifications for a given weapon system.

The subtechnical areas discussed under this subdiscipline are defined in table SS–A.

RADAR REFLECTIVITY

Significant reductions in broadband, low-penalty, radar cross section (RCS) can be made in the design of aircraft by shaping and carefully applying radar-absorbent materials. Recent applications of absorbent material to observation helicopters have shown a significant reduction in RCS. Further evaluation of materials and improved application techniques are required before operational use. Shaping studies have shown basic reduction in RCS is possible and further analysis is required to define structural tradeoffs; i.e., weight, cost, etc. Emphasis is being placed on reducing the RCS of rotor blades (both main and tail) to counter the threat of moving target indicator mode of search and tracking-type radar systems. Further improvements in concepts and application of RCS reduction to dynamic components are required. The trend curve in figure SS–2 shows the potential reduction in RCS of rotary-wing aircraft with respect to frontal exposure.

When tactics call for nap-of-the-earth flying the survivability contribution of RCS reduction against the current known threat has been assessed; this assessment indicates a significant capability for increasing survivability is possible. Further analysis and experimental hardware evaluation of this tactical

TABLE SS–A
SUBTECHNICAL AREAS – REDUCED DETECTABILITY SUBDISCIPLINE

RADAR	• **Pertains to definition of radar reflectivity (echo) of aircraft systems. Selection of echo reduction in relation to active systems (jammers) is studied, and is dependent on threat system and deployment.**
INFRARED	• **Pertains to definition of IR emissions from turbine engine and aircraft systems.** • **Development and selection of reduction techniques and hardware design is based on threats analyzed for required counter-measures.**
VISUAL	• **Pertains to the investigation and definition of aircraft features that provide significant visual detection cues. Concepts and techniques are developed and field evaluated. NOE mission profiles form a baseline for effectiveness evaluation of detection reduction.**
LASER	• **Pertains to the evaluation of developing laser threats and the development and evaluation of material application to aircraft systems to provide reduction of laser damage and detection.**
ACOUSTIC	• **Pertains to the definition and measurement of rotary wing aircraft acoustic signature.** • **Analysis of noise propagation, noise reduction, and trajectory management are conducted to evaluate survivability effects.**

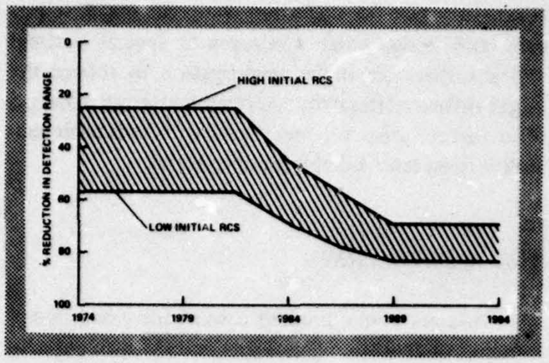


Figure SS–2. Radar cross section reduction trend – frontal aspects.

mode is in process. The development of prediction techniques for helicopter RCS is under way and will require continued comparison to measured data for refinement and increase of confidence levels. Continuing analysis of existing and anticipated threat radar systems is required to determine the most effective approaches for countermeasures.

RCS reduction alone cannot provide complete protection against radar-controlled weapons or surveillance. It can provide (at minimum cost in space, weight, and power effectiveness) broadband reductions in radar return, thus decreasing the range at which the aircraft can be detected or acquired as a target and significantly reducing the space, weight, power, and complexity of complementary active electronic countermeasures where required. Continuing effort is required to determine target levels of passive and active countermeasures for each aircraft system to provide the most efficient package against known and anticipated threats.

INFRARED EMISSIONS

Exhaust Plume Radiation. Initial investigations of turboshaft exhaust plume radiation characteristics, methods for prediction of radiation levels, and methods or techniques for reduction of plume radiation have been completed. Further efforts, as outlined below, are required:

- Evaluation of plume suppression hardware as it applies to the concept of radiation reduction.
- Improved definition of cross flow interaction with exhaust plume is necessary to define conditions for predicting infrared emissions.
- Assessment of the developed plume prediction program for accuracy against a variety of measurement data to improve confidence levels.

Hot Metal Radiation. The discussion on this subject contains CONFIDENTIAL material and is presented in the Classified Supplement to the Plan.

Technological Efforts. A continuing emphasis, as technology changes, is required in the following areas:

- Application (scale up or down) of existing IR suppression technology to inventory aircraft.
- Improved definition of threat weapons characteristics to assess properly countermeasures capability.
- Updating of infrared measurement and analysis procedures. Suppressed levels of turboshaft engines and airframe radiation require more sensitive instruments in order to define and evaluate properly the application of IR-suppression techniques.
- Improved operational analysis procedure and experimental verification techniques to evaluate missile and aircraft engagement and determine the probable level of survivability.

VISUAL DETECTION

In general, visual countermeasures against an optical tracker or weapon aid are rather limited because both devices operate on contrast difference. Trackers can either be mechanically scanned optics or combinations of electronics and optics. Target characteristics that can be used for tracking are: contrast with background, point-to-point contrast across the target, and active lights on the target.

Visual detection investigations show that the mechanism of detection of helicopters at ranges up to about 1-1/2 km by the unaided eye are primarily attributed to:

- Sound
- Motion
- Color
- Size

Any one of these characteristics is sufficient for detection. The important visual detection cues in the 1-1/2 to 3 km range are:

- Canopy sun reflections
- Rotor flicker
- Fuselage shape
- Motion
- Contrast

Statistically significant differences in probability of detection or detection distance occurred when certain countermeasures were used. Listed in order, with the most effective first, they are:

- Flat paneled canopy
- Open structure tubular tail boom
- Color

Greater reductions in detection takes place when these countermeasures are used in combination. From 1-1/2 to 2-1/2 km, contrast is a significant visual detection characteristic. Pattern painting has no beneficial effect. At ranges greater than 2-1/2 km, color and pattern have an insignificant influence on visual detection, provided it is not in sharp contrast to its background. The distance between the aircraft and the background is very important, especially in lower visibility conditions. The helicopter is easier to detect as it moves farther away from the background. Rotor flicker is a significant cue and further investigation is required to reduce rotor glint and define combinations of low glint canopy designs.

LASER DETECTION

The following types of laser systems are presently in development or operationally in use:

- Rangefinders
- Illuminators
- Designators
- High-energy beams (material damage)

Laser threats can be placed in two general classes, each requiring its own form of countermeasures: those laser threats that rely on one-way transmission of energy to a vulnerable target (direct attack); and those laser threats that rely upon reflected energy from the target for operation (rangefinders, illuminators, and designators). Concepts of special coatings and absorbers are under investigation to reduce the target diffuse reflectivity. Aerosol scattering concepts offer further areas for investigation to reduce detectability from laser aided weapon systems.

AURAL DETECTION

Efforts are being directed toward increased understanding of acoustic phenomena and the influences of various acoustic signature levels on aircraft survivability. The worth of attaining reduced aural detection distance through reduced helicopter noise levels must ultimately be assessed by a survivability payoff. Conversely, a survivability level can establish the allowable aircraft noise levels. Recent studies of visual detection show a marked decrease in visual acquisition ranges when the aural cue is missing. The thrust of aircraft noise studies is directed toward the helicopter due to the Army's heavy dependence on rotary-winged aircraft.

Present noise reduction technology can reduce helicopter detection distances, but results in significant loss of aircraft performance. Consequently, accurate and realistic acoustic requirement criteria are essential. A study has been conducted that equates noise reduction with survivability and uses the aircraft aural detection "footprint" to alert weapons and compute kill. (See figure SS–2 in the Confidential Supplement for some trends in research and development relating to acoustic signature reduction.)

Field evaluations and studies have addressed the propagation of aircraft noise and its effects on listening troops. Other studies have investigated pilot-influenced noise control (trajectory management) and ambient noise level influences on the listener. Future effort is needed to further develop refinements of studies in transmission path technology, subjective factors, mission analysis, and weapon capabilities.

TOPICS SUMMARY

The various areas of research pertaining to survivability through reduced detectability that are required to develop this technology are summarized below. Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart SS–I could be achieved.

Radar Reflectivity

- Investigate new concepts of radar attenuating material for application to primary structure: rotor blades, fuselage, etc.
- Develop model, component and full-scale testing of RAM to evaluate application techniques, shaping and cross-section reduction of radar signature.
- Conduct coordination studies to determine the relative feasibility of fixed RAM versus addition of active ECM.
- Design, fabricate, and test advanced concepts low radar cross section to provide off-the-shelf technology for new mission systems.
- Conduct investigations to evaluate the effects of shaping to reduce RCS on helicopter fuselage weight.

Infrared Emissions

- Integrate IR suppression concepts and hardware technology into development of turboshaft engines.
- Conduct analytical and experimental investigations to determine cross flow exhaust plume interactions and radiation reduction effects.
- Investigate inherent cycle characteristics of turboshaft engines with IR signature.
- Develop analysis and design guide for application of IR suppression technology.
- Design, test, and verify conceptual hardware systems to minimize IR emission.

Visual and Laser Detection

- Conduct investigations to evaluate effective countermeasures against visual, laser/electro-optical directed weapons and high-energy lasers.
- Investigate aerosol scattering applications for optical countermeasure systems to determine the optimum systems for satisfying mission needs.
- Provide optical and laser countermeasure design concepts for application to new mission systems and inventory retrofit.

Aural Detection

- Develop detectibility criteria and conduct detailed analyses of operational conditions to determine initial detection levels and resulting survivability.
- Conduct survivability analyses to balance value of reduced acoustic detectability against change in aircraft performance.
- Conduct flight evaluation of Army aircraft trajectory management to determine quiet modes.

SURVIVABILITY THROUGH AIRCRAFT AND AIRCREW PROTECTION

GENERAL

This area includes the research and development of protective measures for Army aircraft and aircrews against ballistic ammunition and antiaircraft fire by application of lightweight armor materials and design techniques derived through research investigations.

TECHNICAL DISCUSSION

Vulnerability reduction technology is intended to increase Army aircraft survivability by minimizing the consequences of damage caused by a projectile hit. It includes reducing probability of attrition (crash), forced landing mission abort, and personnel casualty as well as reducing downtime for damage repair. Significant projectile threats include all known explosive projectiles launched from infantry rifles through automatic cannon, contact fuzed shell as well as the fragmentation and blast effects of larger ballistic or guided weapons. The mechanisms of kill include fire blast penetration and all other means of failing or degrading the critical functional systems or components of aircraft including structure, fuel, flight controls, propulsion, drive trains, crew armament, mission equipment, and cargo.

To protect Army aircraft and aircrews against ballistic ammunition and antiaircraft fire by application of lightweight materials and design techniques, research investigations must include vulnerability analyses of aircraft, systems, and components to determine initial protective requirements against advanced weapon systems and to progressively improve protective techniques.

Primarily, the basic vulnerability data is obtained from experimental testing, analysis, and studies to determine the means of increasing the survivability of Army aircraft (primarily helicopters) employed in forward area operations, wherein they are subject to attack from a wide variety of weapons.

Second, the reduction in weight of ballistic damage tolerant materials suitable for protection of current and future aircraft and their crew are investigated. This effort includes research and development of opaque and transparent ceramics, composite metals and plastics; processing and fabrication methods; ballistic testing; performance evaluations; obtaining armor materials design data; and technical information dissemination.

The basic vulnerability data and the lightweight ballistically tolerant aircraft materials generated above are used to formulate a third consideration: effective design criteria for aircraft and crew protection.

However, upgrading the three technologies is a continuing process. For example, the 23 mm high-explosive projectiles and other ordnance encountered in midintensity warfare are very significant threats to future airmobile operations. Current and nuclear threats have been defined and considerable data exists on blast, thermal radiation, and electromagnetic pulse (EMP) effects on aircraft. Little work has been done toward providing aircraft protection or to defining quantitative tradeoff parameters. High-energy lasers could become a major threat to low-altitude airmobile operations in the 1980s. Limited activity is underway for detecting laser sources and for protecting crew and critical areas.

TOPICS SUMMARY

The various areas of research required to develop technology for reduced vulnerability to combat damage are summarized below. Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart SS–I could be achieved.

Fuel Systems

- Conduct system studies of methods for detection of fuel vapors and fuel system punctures, including automatic jettison.
- Conduct vulnerability studies of fuel and fuel/air vapors to assess hazards.
- Conduct studies to predict ram pressure in fuels and methods of attenuation.
- Design, fabricate and test fuel tank materials for resistance to ballistic damage.
- Develop design criteria for ballistic protection of all systems.
- Conduct research on blast effects from high-explosive projectiles.
- Design, fabricate and flight test prototype fuel systems for system compatibility.
- Conduct ballistic tests on prototype fuel system to substantiate suitability for mission systems.
- Continue studies and tests to evaluate new threat levels and effects on all mission subsystems and overall mission performance.

Flight Control Systems

- Develop fibrous composite materials that can be fabricated into control components that accommodate bullet damage.
- Develop dual hardness servoactuators to defeat small arms with little weight penalty.
- Design, fabricate and test ballistic-tolerant control systems under dynamic and static loads.
- Design and flight test ballistic-tolerant control systems configured for specific mission system.

Dynamic Systems

- Develop materials and coatings suitable for gears and bearings for unlubricated operation for a minimum of 2 hours.
- Develop lightweight, high-strength composites specially suited to accommodate ballistic damage: for application to rotor system.
- Design, fabricate and laboratory test transmission systems that can accommodate ballistic damage of specified threat level.
- Provide off-the-shelf technology for engineering design of highly survivable transmission systems.

Aircrew Stations

- Conduct wound assessment studies of the human body to determine transient depression tolerance.
- Develop lightweight materials suitable for crew seats to defeat fragments and debris.
- Develop dual hardness materials for integral armor applications.
- Develop transparent materials to defeat specified threats with minimum spall and debris.
- Design, fabricate and test armor systems to provide off-the-shelf technology for new mission systems.
- Design and fabricate ballistic test integral armor shells.

Vulnerability Analysis

- Develop/assemble vulnerability analysis methodologies, programs and techniques.
- Conduct analysis of current and developmental aircraft systems to determine levels of vulnerability and establish a vulnerability index for each aircraft versus threat weapons.
- Identify the major vulnerability contributors of each aircraft system and suggest design changes for improvement.

Other

- Develop structural criteria and techniques for aircraft and aircrew protection against nuclear weapons and high-energy sources.

SAFETY

OPERATIONAL FLIGHT SAFETY

General. Operational safety is interrelated with reliability (as well as training and human factors), since operational safety depends on the continued functioning of components and subsystems during flight. In addition to the identification of critical subsystems and components for improved in-flight reliability, emphasis must be placed on devices and techniques to provide crew information that will prevent the increasing incidence of accidents due to the incorrect assessment of conditions.

Operational Hazards. Analysis of aircraft accident statistical data reveals that a significant number of accidents are attributable to operational hazards, many of which could be eliminated or minimized through the application of sound design practices during the early design stage of aircraft weapons systems.

In the past the Army has conducted a very limited effort in this area because of the lack of funds; however, certain operational hazards that cause or contribute to Army aircraft accidents have been identified. One effort needed to reduce the operational hazards is the design, development, and evaluation of a helicopter gross weight and center-of-gravity indicator system applicable to US Army utility and cargo helicopters. The development and qualification of this system could provide the crews of Army helicopters with an accurate and reliable indication of aircraft gross weight and center of gravity location prior to takeoff. Other problems associated with NOE flight include tail rotor and main blade strikes, which often are attributed to pilot error; however, strike-tolerant blades could prevent incidents from becoming major accidents, with attendent injuries and fatalities. In other areas, the pilot's ability to cope with unusual conditions is often affected by overgross loading, power limitations, control limitations, and lift margins usually initiated by operations in off-design circumstances.

Emergency Escape. Many fatalities and injuries occur to aircrews because they cannot escape from an aircraft in an inflight emergency. A review of operational experience and aircraft accident statistical data clearly indicates that a large percentage of aircrew fatalities could have been prevented through the use of an adequate escape system during inflight fire, midair collision, etc. Emergency crew escape techniques and capabilities for aeronautical vehicles exist in the form of bailout parachutes, ejection seats, encapsulated seats, and escape capsules. Ejection and extraction-type escape system components developed for conventional fixed-wing aircraft are available for rotary-wing aircraft; however, new techniques may have to be developed for ejection from rotary-wing aircraft. Conceptual studies and limited experimental testing have also been conducted on sidewise and L-shaped trajectories for extraction of aircrewmen from helicopters through the use of propellant-actuated devices. Application of conventional upward ejection (or extraction) techniques is not yet considered feasible until the undefined effects of rotor

disposition have been established. The various techniques for crew egress from rotary-wing aircraft are currently considered as high risk until the concepts proposed have been subjected to experimental verification. The nap-of-the-earth operational concept further complicates the technological development by placing more severe operational requirements (low altitude, nearly zero reaction time, aircraft attitude, etc.) on the system, while at the same time actually increasing the need for such a system.

An exploratory development program can be implemented that will consider the extreme conditions under which a VTOL emergency crew escape system must function. This program would include the formation of concepts and techniques involving trajectory control for an escape system; aircraft attitude reaction horizon seekers; explosive sequence control systems for multimode operation; emergency sensors; and rapid-action, fully automatic escape system initiation and operation.

Flight Safety Plan. The objectives of the operational Flight Safety Plan are to develop concepts and criteria for the design of equipment and safety devices that, when retrofitted to current aircraft or incorporated in developing or future aircraft weapon systems as will reduce or eliminate the incidence of Army aircraft accidents due to operational hazards incurred as a result of the environment in which these aircraft operate.

A continuing analysis can be conducted to identify and isolate, on a system/subsystem basis, critical design deficiencies, techniques, and operational hazards that frequently cause or contribute to Army aircraft accidents. Analytical techniques can be developed to predict and isolate potential safety hazards early in the life-cycle development of future Army aircraft weapon systems. The design deficiencies identified through such an analysis can be used to formulate specific development programs under system safety programs.

CRASHWORTHINESS

General. Crashworthiness involves the development of techniques for minimizing the crash effects on crew and passengers and reducing the high replacement costs of aircraft and components. Crashworthiness R&D seeks to eliminate or reduce crash hazards (other than postcrash fire) that cause occupant injury during aircraft crash impacts. A major facet of crashworthiness is structural crashworthiness (i.e., the ability of the aircraft structure to maintain a protective shell around occupants during a crash and to minimize accelerations applied to occupiable portions of the aircraft during impact). Other facets of crashworthiness include occupant retention systems, delethalization of cabin and cockpit volumes, postcrash emergency ingress/egress provisions, and retention of ancillary equipment carried onboard the aircraft.

During the early and middle 1960s, numerous accident investigations, full-scale crash tests, and evaluations of fixed- and rotary-wing aircraft were conducted. The results verified that Army aircraft of the late 1950s and early 1960s were designed for airworthiness alone, with little or no emphasis placed on the crash survivability aspects of aircraft design. Sufficient data has been generated on crash kinematics and kinetics to permit (1) statistical definition of crash impact conditions, and (2) identification of crash hazards and design inadequacies for aircraft designed in the 1950s and early 1960s. Accident analysis for that period revealed that approximately 95 percent of the injuries and 50 percent of the fatalities in Army aircraft accidents were occurring in potentially survivable accidents; moreover, approximately 94-96 percent of all accidents were potentially survivable. This figure included postcrash fires, which accounted for approximately 40 percent of the fatalities and which have essentially been eliminated by technology advances during the early 1970s. Another 47 percent were from impact trauma, for which technology is still being generated.

Preliminary design criteria and concepts for improved aircraft crash survivability design have been established and published in USAAMRDL TR 71-22, "Crash Survival Design Guide." MIL-STD-1290AV has been published for light fixed-wing and helicopter crashworthiness.

Recent research and exploratory development efforts have resulted in significant technological advancements in the areas of load-limiting devices, crashworthy crew seats, restraint systems, and aircraft structural crashworthiness analytical techniques. It has become evident that more refined engineering criteria and designs are needed in the crash survivability areas of seats, airframe, cargo tiedown, litters, landing gear, ancillary equipment tiedown, energy absorption methods/devices, and materials before the advanced

and engineering development efforts can be conducted with acceptable risk.

Crashworthiness Criteria. The objective of the crashworthiness program is to develop design criteria and optimize the design of aircraft components and items of personal equipment to the extent that present and future Army aircraft will provide the maximum protection to occupants in an aircraft accident and minimize the loss of lives, material, and mission performance.

Crashworthiness Goals. The quantitative measure of crashworthiness can be expressed in terms of injuries per potentially survivable accident and fatalities per potentially survivable accident. The trend goals for these ratios (figure SS–3) show that the first major reduction in both injuries and fatalities resulted from retrofit implementation of crashworthy fuel systems. The second reduction, beginning about FY80, reflects the anticipated rate with the introduction of the UTTAS and AAH, which incorporate crashworthiness design criteria into the basic aircraft design criteria.

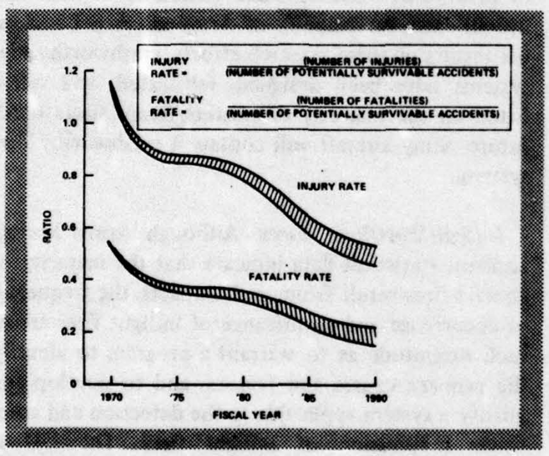


Figure SS–3. Crashworthiness improvement goal.

Technical Discussion. A continuing program can be conducted to improve the analytical tools available to the aircraft crashworthiness engineer so he can more easily and accurately determine how structures or devices will behave when loaded dynamically to plasticity and failure. This program will include development of a three-dimensional mathematical model capable of predicting the biodynamic response and injury potential of crash impact loading of seated occupants.

The advent of the armed helicopter within the Army introduced an additional safety hazard, that of providing protection in the crash environment to those crewmen performing gunner duties. An effort has been conducted to develop design criteria and preliminary seat designs that can provide occupants with the maximum degree of protection during survivable accidents.

A program is being conducted to design, fabricate, and test prototype models of side-, aft-, and forward-facing troop seats with integral restraint systems, in accordance with a draft military specification based on USAAMRDL TR 71-22. The draft military specification can then be revised, as necessary, and advanced development conducted using the best design concepts.

The restraint of cargo aboard an aircraft is very important in a survivable crash to prevent injury to crew and passengers. However, restraining devices of sufficient strength to preclude breaking or tearing in a crash are useless if the tiedown points and surrounding structure are not of sufficient strength to withstand the imposed loads. Therefore, improved structural strength is needed at critical points to withstand survivable crash loads. A program can be conducted to design, develop, test, and evaluate candidate cargo restraint system designs and improved support structure in an effort to restrain cargo in a survivable aircraft crash. Tests have been conducted to verify the military specification and a troop restraint system can be developed which is superior to the existing system.

Aircrew restraint systems have progressed from the single lapbelt to the more sophisticated and protective systems containing inertia reels, shoulder straps, belt tiedown straps, and lateral restraint straps. The latest system, which has been completed under static and dynamic testing, provides the maximum protection possible within current technology for systems of this type. To eliminate the remaining deficiencies of this system, an advanced aircrew restraint system can be developed that will be comfortable, lightweight, practical, and provide protection to the wearer during survivable aircraft crashes beyond the conventional belt/webbing/buckle-type systems. A troop seat restraint system study has been accomplished to produce a draft troop seat restraint system military specification as well as an experimental prototype design.

During the past 10 years, numerous crashworthy design concepts have evolved from the investigation of aircraft accidents and from the conduct of dynamic crash tests. Many of these concepts represent a radical departure from conventional design practices and verify the need for a program to demonstrate the effectiveness of the designs and determine the feasibility and the practicality of their use in future Army aircraft. A recent effort developed rotary-wing landing gear concepts and preliminary design criteria to lessen the magnitude of crash forces being transferred to the occupiable area of helicopters involved in severe, but survivable, accidents without producing failure loading on the airframe. The results can be applied to the design, fabrication, and testing of an experimental prototype landing gear for a specific aircraft; subsequently, landing gear specifications applicable to all future Army aircraft procurements can be revised. During 1969-1970, a mathematical nonlinear lumped mass model having 23 degrees of freedom was developed to simulate the response of a helicopter airframe to vertical crash loading. Current efforts can result in the development of a computerized rotary-wing aircraft model that predicts dynamic response to combined vertical and lateral loads. These efforts will be expanded to consider all components of the typical crash pulse.

Because of recent interest in aircraft and automobile crashworthiness, numerous energy-absorbing devices have evolved; however, only limited mechanical and physical data are available pertaining to them. A continuing program will be conducted for the purpose of (1) developing energy-absorption devices to meet the needs of crashworthy subsystems and systems, (2) evaluating, through analysis and testing, the crashworthiness potential/disadvantages of materials (particularly composite materials) and energy absorbers, and (3) evaluating the capability of energy-absorbing devices to function reliably in the Army aviation environment. Emphasis will be placed on developing higher energy absorption capabilities, lower weight, and improved R&M characteristics. Also, potential crashworthiness applications for air bag devices will be investigated.

Periodic revision (approximately biannually) of the "Crash Survival Design Guide" can be continued to reflect not only the results of this program but also structural crashworthiness programs conducted by industry and other Government agencies.

Primary goals of this task are to evaluate new aircraft systems and to conduct design studies to determine efficient ways of coordinating the various crashworthiness design techniques. Because of the numerous new Army aircraft systems currently planned, the need is essential technical support in the form of criteria that interface with other disciplines, proposal evaluation, crashworthy analytical evaluation, and dynamic testing of the systems as test vehicles become available.

POSTCRASH HAZARDS

Fire Prevention. Fire prevention involves the development of techniques for prevention of the incidence and propagation of fire after impact. The aircraft fire prevention program is to develop procedures and techniques that will minimize potential ignition sources, limit the propagation of fires that do occur, and provide fuel and flammable fluid containment systems that are optimized from the standpoint of crashworthiness.

For the past several years, a comprehensive theoretical and dynamic test program has been conducted to develop new concepts and criteria to improve the overall crash survivability of Army aircraft. Based on the results of these research efforts, crashworthy fuel systems have been designed, fabricated, and retrofitted on the majority of existing Army aircraft. All future Army aircraft will contain a crashworthy fuel system.

Inflight/Postflight Fires. Although Army aircraft accident statistical data indicate that the majority of aircraft fires result from crash impacts, the frequency of occurrence and significance of inflight fires are of such magnitude as to warrant a program to identify the primary causes and factors, and to develop and qualify a system applicable to the detection and automatic suppression of inflight fires. The UH–1, AH–1G, and CH–47 were investigated to determine the major causes and contributing factors of inflight fires in the combat and noncombat environment, and a breadboard model of a detection and suppression system was fabricated and tested. Safety benefits will accrue through system improvements such as these, but the safety characteristics of the fuel itself must be improved before postcrash fires are completely eliminated. Research efforts have demonstrated that some types of modified fuels are generally compatible with current aircraft fuel system components. Fire-resistant hydraulic fluid has also been developed and is being evaluated in Army aircraft.

Quantitative measurement for aircraft fire prevention and reduction in injuries/fatalities is expressed in two ways: in the percent probability of an inflight fire when the fuel system is impacted by an incendiary round; and in the suppression of fire onset following a crash for a period of time (normally expressed in seconds) allowing occupants safe egress. Trend goals for these factors are shown in figures SS–4 and SS–5.

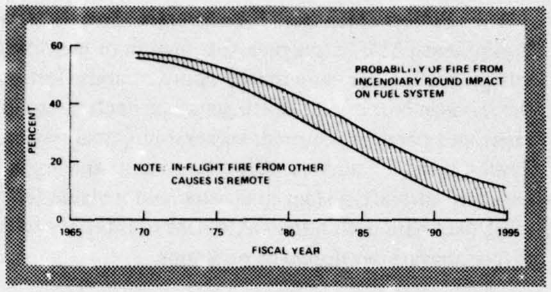


Figure SS–4. In-flight fire prevention improvement goal.

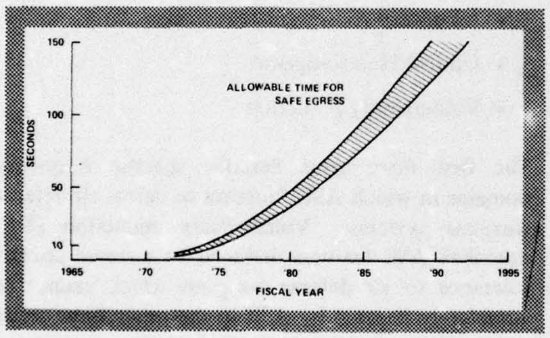


Figure SS–5. Postcrash fire protection improvement goal.

The installation of the crashworthy fuel system on current Army operational aircraft offers the potential of greatly decreasing the incidence of postcrash fire and reducing the number of thermal fatalities sustained in survivable accidents. The crashworthy fuel system currently being installed pertains only to the containment of the fuel and does not provide containment for the oil and hydraulic system (which is further complicated by higher system pressures). The development of a crashworthy flammable fluids system and an ignition control system will reduce the incidence of postcrash fire; however, before attaining complete elimination of fires, the safety characteristics of all flammable fluids will have to be improved.

Postcrash Emergency Egress. In view of the success of the crashworthy fuel system in the prevention of postcrash fires, other postcrash hazards that injure or kill occupants of Army aircraft following what would otherwise be a survivable accident, should be considered during the design of future Army aircraft. An R&D program could provide design criteria and military specification revisions that would increase survivability of accident occupants from such hazards as exposure, drowning, and slow propagating fires through improved egress passages, procedures, and access openings.

TOPICS SUMMARY

The various areas of safety research that are required to develop this technology are summarized below. Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart SS–I could be achieved.

Operational Flight Safety

- Conduct studies to determine maximum tolerance to loads on the human body.
- Conduct energy attenuation studies on deformable materials.
- Conduct studies of methods for egress from V/STOL aircraft in flight and design, fabricate and laboratory test subsystems of candidate escape concepts.
- Conduct studies of candidate transducers for application to lift margin systems and develop inflight measurement systems for lift margin parameters: engine power, atmospheric density, gross weight, center of gravity.
- Design, fabricate and laboratory test lift margin systems.
- Study terrain-avoidance systems specially suited to avoidance of wires in flight and establish criteria for design of wire-avoidance systems for inflight operation.
- Conduct a study of revetments for improved design and location to minimize taxi accident.
- Continue development of criteria for flight safety based on a study of operational safety hazards.
- Investigate new vehicle concepts that improve safety through elimination of some components

which have a history of causing mishaps (i.e., tail rotor).

- Improve operational safety through the corrective action process would be greatly enhanced by a crash data recorder which would accurately describe causes and provide a basis for establishment of more precise guidelines for design of survivable aircraft and life support equipment.

Crashworthiness

- Collect and analyze aircraft accident data to identify design deficiencies.
- Develop analytical models representative of aircraft dynamics during actual crash conditions.
- Develop the potential of composite materials for crash attenuation.
- Conduct crash energy dissipation analyses.
- Conduct plasticity and failure analyses.
- Develop and publish new crash survivability design criteria.

Postcrash Hazards

- *Develop new concepts for reducing* or eliminating aircraft fires.
- Establish new ways of eliminating potential ignition sources (electric wire, hot metal, etc.).
- Develop sensors, actuators and inerting devices that will serve as elements of an ignition source control system.
- Determine toxicity and smoke concentration of fire-retardant materials.
- Test and evaluate promising fire-retardant materials under aircraft environmental conditions.
- Determine by data studies and literature search the level of fire hazard from all flammable fluids and potential containment systems.
- Design, fabricate and test fluid containment systems and verify improved crashworthiness.
- Determine capability of current fuel system components to accommodate modified low-ignition fuels.
- Conduct engine tests to determine influence of modified fuels on performance.
- Establish design criteria for increased survivability of accident occupants from postcrash conditions.

AIRCRAFT SURVIVABILITY EQUIPMENT

GENERAL

The Project Manager for Aircraft Survivability Equipment (ASE) is assigned the mission of providing self protection for the current Army aircraft fleet on the modern battlefield; contingency protection equipment and plans as required; vulnerability analysis and development of survivability techniques and equipment for aircraft system managers; and a viable technical data base within the DARCOM to interface with future aircraft development programs.

ASE are categorized into four technological areas:

- Radar
- Infrared
- Optical/Electro-optical
- Vulnerability reduction

The first three areas describe specific frequency domains in which ASE function to defeat air defense weapons systems. Vulnerability reduction (VR) describes ASE features designed to increase aircraft tolerance to air defense weapons which cannot be completely negated by ASE in the other three areas.

The radar, infrared, and optical technological areas can be subdivided into categories of equipment based on techniques used to reduce or deny the use of electromagnetic radiation by air defense systems, i.e., signature reduction, threat warning, and active response. Figure SS–6 illustrates the relationship between ASE technological areas and threat weapon fire control modes.

Signature reduction reduces the level of electromagnetic radiation emitted by or reflected from the aircraft. Threat warning ASE are employed to alert aircrew members that a fire control system is acquiring or tracking/homing in on the aircraft, and/or initiate an active response measure. Active responses are employed to confuse; jam, or decoy fire control systems which have locked on and are tracking the aircraft.

	WEAPON FIRE CONTROL PROCESS					
ASE	**Detection**	**Acquisition**	**Track**	**Fire**	**Fly-Out**	**Damage PK**
SIG REDUCTION						
Radar	•	•				
IR	•	•				
Optical	•	•				
THREAT WARNING						
Radar		•	•	•		
IR			•	•		
Optical			•	•		
ACTIVE RESPONSE						
Radar			•		•	
IR			•		•	
Optical			•		•	
VULNERABILITY REDUCTION						•

Figure SS–6. Relationship of ASE to fire control process.

Vulnerability reduction features are specifically designed to increase the capability of the aircraft to withstand hits from ballistic projectiles and fragments from high explosive projectiles. The extent to which VR may be incorporated into an aircraft system may not be in direct proportion to the severity of the threat from ballistic projectiles since constraints of aircraft performance and cost may prohibit the application of certain VR features. The air defense threat and categories of ASE targeted against the threat are shown in figure SS–7.

ASE DEVELOPMENT PROGRAM

The ASE program must maintain a technology level responsive to changes in capabilities of enemy threat weapons and to changes made possible by state-of-the-art advances. Ideally, Army aircraft would be equipped with effective survivability equipment for immediate deployment against any hostile air defense force. However, the threat intelligence required to provide effective countermeasures is often not available until enemy weapons are committed to battle, compromised, and exploited. Thus, to ensure a high probability that ASE technology will be available when required and to minimize operational risk in the employment of ASE, it may be necessary to concurrently develop several ASE which are considered as alternate approaches to defeating a particular threat or threat class (e.g., infrared jammers and flare decoy/missile detector systems).

THREAT	ASE
Small Arms	Optical Vulnerability Reduction
Anti-Aircraft Artillery (AAA)	Radar Optical Vulnerability Reduction
Missiles	Radar Infrared Optical

Figure SS– 7. Threat vs ASE.

The ASE Project Manager sponsors and monitors development programs for advanced Army aircraft; provides systems analysis and consultation assistance to the AAH, ASH, and UTTAS Project Managers; and maintains state-of-the-art measurements and analysis techniques to generate and validate ASE requirements. The majority of ASE projects are presently in 6.3/6.4 development phase. To ensure that future needs are met, the ASE-PM sponsors 6.2/6.3 programs conducted by the Electronic Warfare Lab (EWL), ECOM, and the Air Mobility R&D Lab (AMRDL), AVSCOM.

The development and procurement of ASE is grouped into two distinct categories:

- Aircraft modifications which constitute a change in aircraft configuration (e.g., signature reduction and vulnerability reduction).
- Black-box components and support/training equipment which either do not function as an integral/essential part of the aircraft or are not aircraft-type peculiar (e.g., IR jammer, radar warning receiver, etc.).

The diversity of current and potential threat systems and the severe size, weight, and power constraints presented by current fleet Army aircraft preclude the development of single, generic ASE systems. Countermeasure techniques are generally widely dissimilar and require development of several equipments, each addressed to countering a specific threat or threat class. The combination of ASE necessary to protect an aircraft during a particular mission is dependent upon the nature of the threat weapon, its density, vulnerability of the aircraft, mission profile, and geographical area in which the mission is performed.

Current inventory aircraft will be retrofitted with ASE systems shown on figure SS–8. ASE for developmental aircraft will be inherent design objectives with retrofit only as required to meet future growth threat weapons. ASE will generally be designed as easy-to-install/remove modules to provide flexibility to configure aircraft for peacetime/training purposes and for combat situations based on specific mission profiles and threat environments.

Where practical, control and display units will be integrated, multifunction components, e.g., a single display unit capable of providing warning indication of a variety of threats. To the maximum extent possible, ASE will be common to several aircraft types to minimize procurement and logistics impact.

Of the four ASE categories, active response devices place the most emphasis on a priori knowledge of threat systems; signature reduction and vulnerability reduction are the least dependent on specific threat intelligence and are therefore the most fundamental approaches to aircraft survivability. From a penalty and cost standpoint, signature reduction and threat warning reduce the space, weight and power requirements of some active response devices. From a risk standpoint, ASE technology is well advanced except for the area of optical threat warning and active responses and radar signature reduction (figure SS–9). In other areas, efforts are centered on integrating ASE devices into optimally effective systems for each type aircraft.

TECHNOLOGY DISCUSSION

Signature Reduction. Aircraft survivability, through reduced signatures, will be accomplished by optimizing the effectiveness of passive measures against multiple threat emitters/sensors utilizing the infrared, visible, and microwave portions of the electromagnetic spectrum.

Infrared suppression of engine graybody (and plume) and secondary graybody emitters; such as transmissions, heat exchangers, and armament will be accomplished to reduce threat weapon acquisition range and to reduce ERP requirements for active response devices.

Paint and coatings will be utilized to reduce solar infrared and visual reflections to the extent that this technique does not increase the visual contrast of aircraft against normal earth and sky backgrounds.

Low glare canopies will be utilized to reduce the incidence of visual glint detection cues and specular solar infrared reflections utilized in tracking and guidance by infrared missiles.

Radar cross section reduction techniques are utilized to reduce the probability of acquisition/detection within the effective range of radar-directed weapons, or to enhance the effectiveness range of active radar response devices.

Threat Warning. Provide initiation of active response devices and/or warning to aircrew to take evasive actions.

AIRCRAFT	EQUIPMENT REQUIRED NOW	EQUIPMENT REQUIRED WHEN AVAILABLE	EQUIPMENT TO BE MADE AVAILABLE FOR INDIVIDUAL AIRCRAFT ON A MISSION REQUIRED BASIS
AH-1G/Q	IR Suppressors Low Reflective Paint Radar Warning Receiver	Low Glare Canopy (IRCM Jammer) Missile Detector + Flare Vulnerability Reduction	Chaff Laser Detector Advanced Radar Warning Receiver
OH-58A, OH-6A	IR Suppressors Low Reflective Paint Radar Warning Receiver	Low Glare Canopy Vulnerability Reduction	Missile Detector + Flare (IR Jammer) Chaff Laser Detector Advanced Radar Warning Receiver
UH-1	IR Suppressors Low Reflective Paint Radar Warning Receiver	Vulnerability Reduction	Chaff (Radar Jammer) Laser Detector Advanced Radar Warning Receiver Missile Detector + Flare (IR Jammer)
CH-47	Decoy Flare Dispenser Radar Warning Receiver	Missile Detector Suppressors (IRCM Jammer)	Chaff Laser Detector
OV-1D	IRCM Jammer Low Reflective Paint AN/ALR-46	IR Suppressor Missile Detector + Flare Vulnerability Reduction	Chaff (Radar Jammer) Laser Detector
RU-21	IR Suppressors Low Reflective Paint AN/ALR-46	Missile Detector + Flares	Chaff (Radar Jammer) Laser Detector

( ) indicates alternate item

Figure SS–8. Required ASE systems.

TYPE ASE	SIGNATURE REDUCTION	THREAT DETECTION	ACTIVE RESPONSE	VULNERABILITY REDUCTION
Radar	Med-High	Low	Med	—
Infrared	Low	Low-Med	Low-Med	—
Optics	Low	Med-High	High	—
Ballistic	—	—	—	Low-Med

Figure SS–9. Technical risk.

Missile detector systems will be utilized in conjunction with flare decoy systems to detect launch or approach of IR-guided missiles and initiate deployment of IR decoys.

Optical augmentation techniques will provide threat identification, direction, and range of optically-directed weapons systems. These devices will have sufficient sensitivity to detect optical trackers at ranges greater than the maximum effective range of the associated weapons system.

Laser warning detectors will indicate the direction of illumination of laser energy; identify the associated threat weapon; and, where possible, the mode of operation.

Radar warning receivers will indicate the direction of radar emitters and identify the associated threat weapon and operating mode. Advanced warning receivers will be capable of processing information from other sensors such as missile detectors and laser detectors.

Active Response Devices. Provide a means to deny or degrade detection, acquisition, fire control, and/or guidance information associated with air defense threat weapons. Active responses will be capable of manual and/or automatic operation in conjunction with threat warning devices.

Chaff/flare decoy dispensing systems will function either manually or automatically in conjunction with a radar warning receiver or missile detector system to defeat or degrade effectiveness of air defense weapons.

Infrared jammers, either fuel-fired or electrical, generate modulated IR energy to produce false target information to IR guided threat missiles. When employed with IR signature reduction techniques, jamming devices can provide significant protection against IR missiles.

Radar jamming equipment will be activated by self-contained receivers when aircraft are illuminated by fire direction/control radar systems. The effective envelope of the jammer will be such that protection is provided within the maximum effective range of the threat weapon system.

Optical contrast reduction techniques will degrade or deny optical detection, acquisition, and/or tracking by actively tuning the optical contrast of the aircraft into the background at ranges within the maximum effective range of the associated weapon system.

Vulnerability Reduction. Selected aircraft components will be ballistically hardened to increase aircraft survivability against 7.62 mm API, 12.7 mm API, 23 mm API, and 23 mm HE projectiles.

TECHNOLOGICAL PROGRAM DISCUSSION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the safety and survivability discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget. The AVSCOM ASE effort is not included in this discussion.

OBJECTIVES

The near-term program objectives for the various subdisciplines within the S&S discipline can be established from the near-term quantified achievement goals listed in chart SS–1. These objectives will directly improve system performance, thereby reducing life cycle costs and improving the intrinsic value of the system to save human lives. The S&S objectives are:

- Improve survivability rate to 65%.
- Reduce acoustic detection time to 50 seconds or less.
- Reduce vulnerability to projectiles to 10%.
- Reduce accident rate to 9 per 10^5 flight hours.
- Reduce survivable accident injury ratio to 0.85 and fatality ratio to 0.35.
- Decrease incendiary fire probability to 45%.
- Increase survivable egress time to 25 seconds.

PROGRAM PRIORITIES

General. Table SS–B presents, in a prioritized listing, the S&S technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The S&S technology subdisciplines are represented by the major topical as presented in table SS–C.

Vehicle Subsystems. Vehicle subsystems, as related to S&S technology, are categorized as follows:

- Rotor systems
- Engines and fuel system
- Airframe
- Avionics
- Personal equipment

System Effectiveness. In the area of system effectiveness, the primary impact of safety and survivability technology is on life cycle cost and vehicle effectiveness. In the life cycle cost area S&S plays a key role in development, flyaway and attrition costs; while in vehicle effectiveness, S&S is most prominent in the determination of aircraft safety, survivability, and reliability.

Priorities. With reference to table SS–B, the S&S subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

The major thrusts in the area of safety and survivability are:

- Development of countermeasures to increase survivability by reduced detectability to enemy sensors of the vehicle subsystems/systems.
- Development of aircraft components/ subsystems tolerance to enemy ordnance to increase survivability.
- Development of crashworthy aircrew ballistic protection subsystems to improve safety.

These thrusts are supported by the following rationale:

- From an assessment of the priority listing in table SS–B and the near-term objectives stated above, it can be seen that survivability depends on, more than any other parameter, the detection time variation (DTV) between the aircraft and enemy threat forces. Therefore, the first priority is to reduce aircraft signatures to an acceptable level. The amount of R&D effort involved to counter the four means of detection (radar, IR, visual, aural), should be allocated according to the relationship of the amount and effectiveness of the detection method utilized

TABLE SS–B

PRIORITIZED S&S OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Detectability	I	• Rotor systems	I	• Survivability	I
• Aircraft and aircrew protection	II	• Engine and fuel system	II	• Safety	II
				• Attrition cost	III
• Safety	III	• Airframe	III	• Reliability	IV
		• Avionics	IV	• Flyaway cost	V
		• Personal equipment	V	• Development cost	VI

TABLE SS–C

S&S SUBDISCIPLINE MAJOR TOPICAL AREAS

SUBDISCIPLINE	MAJOR TOPICAL AREA
SURVIVABILITY THROUGH REDUCED DETECTABILITY	• Reduced Detectability: Aircraft may be identified and acquired as targets by a variety of techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing systems. Countermeasures against these systems can involve either reduction of the aircraft signature by which it can be identified, by deception, or by using an efficient combination of the above.
SURVIVABILITY THROUGH AIRCRAFT AND AIRCREW PROTECTION	• Reduced Vulnerability: Army aircraft are not only vulnerable to the hazards of normal flying, but are subject to direct hostile attack by enemy forces. In order to develop systems with adequate life cycle costs, it is necessary to increase the survivability of the air vehicle under attack by adding protective armor and/or combat-damage-tolerant structures. • Crashworthiness: Early in the design phase of new aircraft systems, concepts can be incorporated into the airframe to enhance its protection to crew, passengers, and high replacement cost components during a crash.
SAFETY	• In-Flight Safety: This area is concerned with the continued safe functioning of the aircraft components and systems during flight. This includes safe in-flight egress. • Fire Prevention: Analysis of aircraft accident historical data involving fixed and rotary wing aircraft reveals that the greatest number of fatalities occur in accidents involving fire. Fire prevention pertains to reducing this fire hazard and increasing allowable crew egress time.

by threat forces, and the state-of-the-art and effectiveness of Army countermeasures. The reduction of radar cross section (RCS) and infrared signature should be first priority, since radar and IR are the prime means of aircraft detection used by the threat and gives the greatest DTV advantage to the enemy. The state-of-the-art in RCS and IR reduction can be advanced to reduce the DTV advantage of the enemy. With the increasing importance of terrain flying in the high threat environment, aural detection must also be emphasized and should be rated with RCS and IR in importance. Supporting this prioritizing are the benefits to be gained in reducing enemy standoff weapons effectiveness.

- Once an exchange of fire takes place, survivability is enhanced by the aircraft's ability to absorb ballistic damage. Based on the number and type of enemy weapons and components considered critical to continued flight, R&D should be directed to enable those components to receive 7.62 mm, 12.7 mm, 14.5 mm, and 23 mm HEI projectile damage without immediate failure. Those components considered most critical are rotor systems and drive systems. Power plants, by virtue of multiple installations, provide adequate redundancy.

- Combat and operational records show that the aircrew members are the weakest link in the aircraft system from a vulnerability standpoint and the most difficult to protect. Aside from an emotional and moral issue the cost effective use of crew members calls for adequate protection from environmental hazards and an adequate retrieval system in the case of complete aircraft failure. Continued research can improve the state-of-the-art in crew armor protection, crew egress, and crash and fire protection.

LABORATORY PROJECTS IN SAFETY AND SURVIVABILITY

INTRODUCTION

Safety and survivability technological development effort is presently directed toward exploratory development (6.2): to develop techniques for defeating or degrading the effect of known or potential threat weapons and target acquisition devices by aircraft signature reduction and aircraft design; to reduce weapon effectiveness; and to improve crash survivability. All efforts are applicable to future combat aircraft development programs and provide a technological base for the development of UTTAS, AAH, ASH, and RPV.

The development efforts are conducted by the Eustis Directorate of AMRDL by either in-house efforts or by contract. Interface and coordination in areas of interest will be maintained with the user, other Army agencies, the other services (Navy and USAF), the FAA, and NASA.

DESCRIPTION OF PROJECTS

Safety and Survivability Technology. Project 1F262209AH76-TA V is an exploratory development effort to develop advanced technology and design criteria to enhance the effectiveness of Army aircraft in terms of increased survivability and flight safety. Survivability shall include the reduction of detection by IR, radar, optical, laser, and acoustic means and provide aircraft and aircrew protection against ballistic and laser threats. Flight safety shall include operational safety of aircraft and crews through increased crashworthiness of structure and crew seats, prevention of postcrash fire, elimination of in-flight hazards, and provision for emergency egress. The results of this program are applicable to retrofit of current aircraft and development of criteria for design of developmental and future aircraft.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the S&S R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 S&S FY77 R&D effort is 2.04 million dollars and represents 13% of AMRDL R&D 6.2 funds (excluding Project 1F262201DH96 Aircraft Weapons Technology funds).

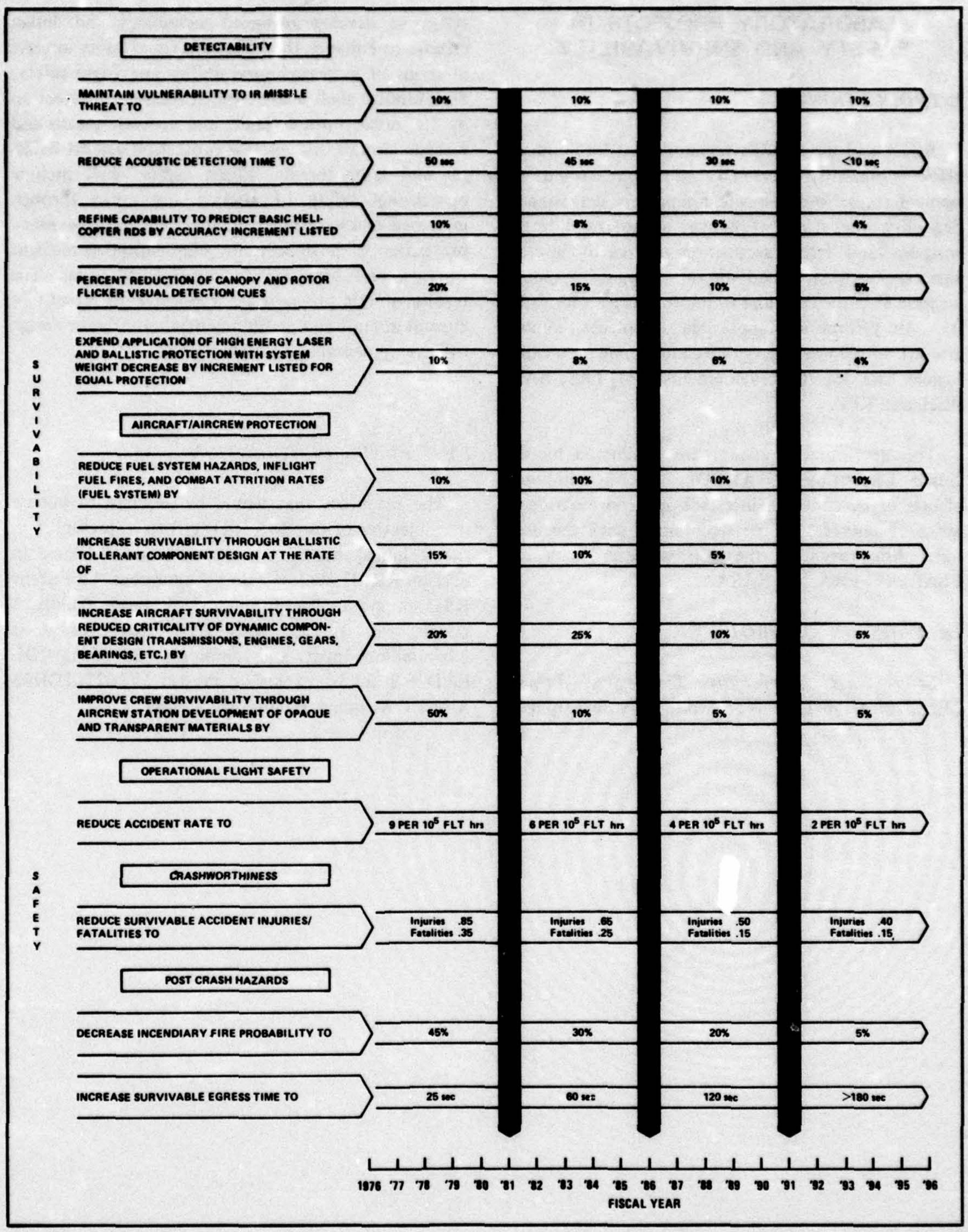
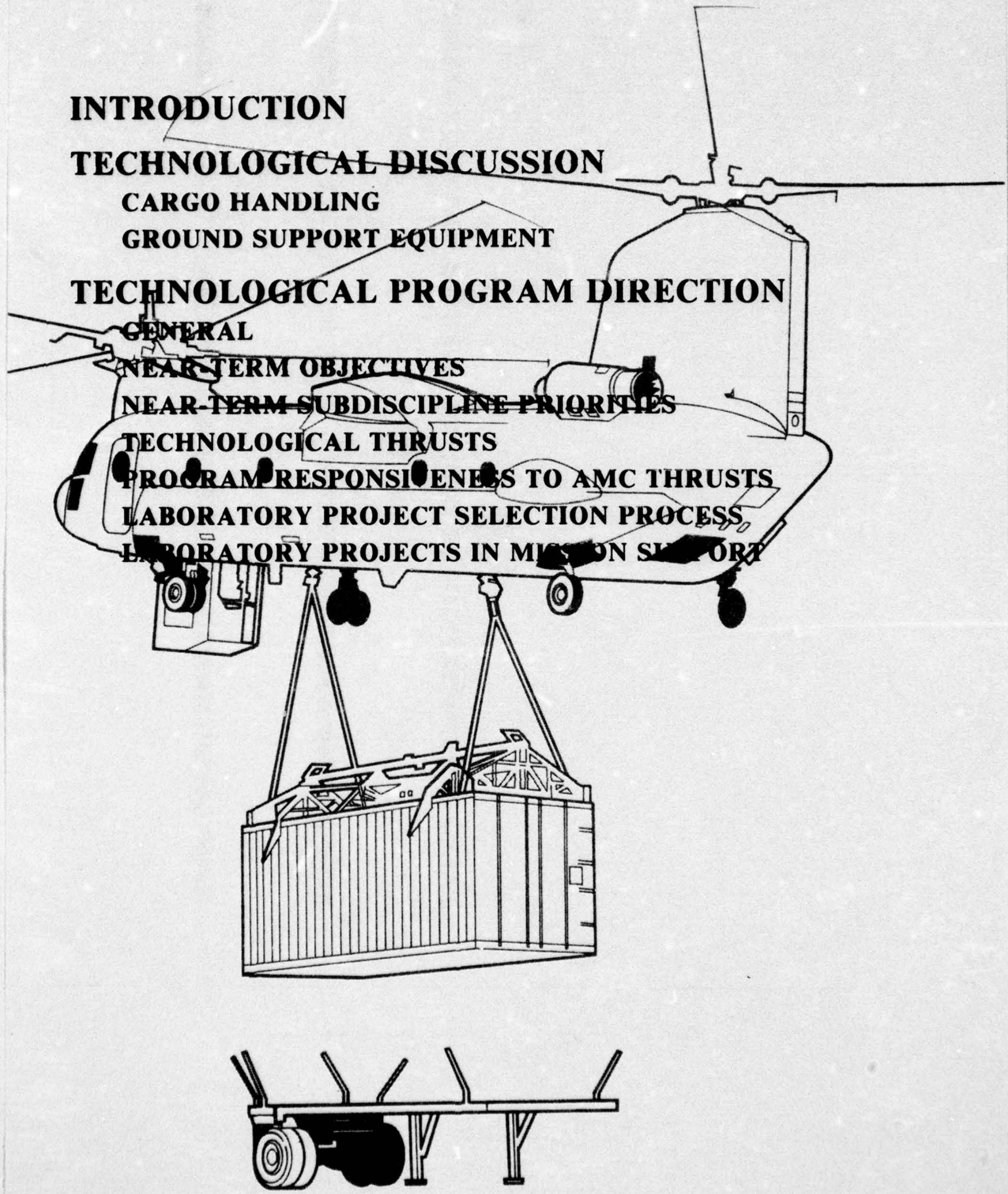


Chart SS–I. Safety and Survivability Achievement Goals.



INTRODUCTION

Mission support can be generally described as those interrelated techniques and disciplines that provide Army aircraft with the capability of expeditiously performing their assigned tasks. To a significant extent, the optimal relationships among the provisions required for accomplishing these tasks determine the success or failure of the mission, the aircraft's productivity, and even its survival.

Army airmobile systems exist to assist the ground commander in conducting one or more of the functions of land combat: mobility, intelligence, firepower, combat service support, and command, control and communications. In the contents of the Army Aviation RDT&E Plan, mission support equipment is that ancillary equipment necessary to permit the aircraft to perform a specific mission or to support the aircraft during a specific mission. This section of the Plan covers the mobility and combat service support functions, while intelligence, command, control, and communications are covered in the section on aviation electronics; firepower is covered in the aircraft weaponization section.

The effectiveness of the aircraft system is largely determined by the effectiveness of the subsystems for the mission. Thus, the ability of the aircraft to acquire and deliver loads or intelligence, or acquire and destroy targets, is the primary justification for the aircraft.

The mission subsystems have close and important interrelationships with the other subsystems of the aircraft and with other disciplines, such as aerodynamics, structures, and propulsion. As the Plan is concerned with technology development resulting in cost-effective, superior airmobile systems, the results of R&D programs in mission support systems are equally significant as the R&D results in the other disciplines.

The mission support functions discussed in this subsection with accompanying graphs and charts describe specific goals and programs needed to provide the best off-the-shelf technology to serve the need of Army airmobile systems, present as well as future.

The overall R&D efforts related to mission support technology discussed in this section are shown in chart MS–I (located at the end of this section). The application of the technological improvements is keyed to near-term, mid-term, and future systems. However, any improvement could be applied to existing aircraft through PIP programs.

TECHNOLOGICAL DISCUSSION

CARGO HANDLING

GENERAL

Historically, the major effort in aircraft system technology R&D has been in the basic disciplines (aerodynamics, structures, propulsion, etc.). In addition, mission systems for weapon deployment and surveillance roles have received extensive R&D activities to optimize system hardware and techniques to support these missions. However, for aircraft having primary combat support missions of delivering men, supplies, and equipment, too little emphasis has been placed on the means by which these missions can be performed efficiently and effectively. As a result, technologies relating to cargo handling are lagging that of the basic aircraft and is a pacing factor in the ability of the aircraft to perform its mission. The Science and Technology Objective Guide recognizes this deficiency and assigned a high priority to the development of cargo handling capabilities which will permit external loads to be transported without restricting the aircraft envelope or operational capabilities, and to permit hook-up and drop-off of cargo without ground crew support.

The principal performance capabilities of the aircraft, which have been achieved at very high costs, can be seriously downgraded by out-of-date cargo handling technology. For example, the ability of a cargo helicopter to fly in all weather conditions may be of little value unless it can also pick up and discharge its payload under the same conditions. With current technology, a helicopter carrying an external payload is sometimes slowed to speeds of less than 40 knots to avoid hazardous instabilities of the payload. The effectiveness of increasing aircraft cruise speed is also reduced by the long hover times sometimes required to acquire and deposit the payload. These factors, coupled with poor reliability, excessive weight, and hazardous conditions for ground personnel, emphasize the need for a continuous systematic effort to improve cargo handling subsystem technology.

Recent advances in cargo handling R&D provide technologies that have high potential for significant improvements in combat and logistical support operations – specifically in areas of sling systems, load stabilization, and load acquisition. There remain a number of unmastered disciplines that have major impact on these functions. In addition, the advent of a high air defense threat environment introduces a new dimension to the combat support mission, with its attendant needs for new technology. The categorization in table MS–A represents the most pressing challenges to mission support roles for contemporary and future rotary-wing aircraft; these roles are discussed in appropriate subdiscipline areas of this section.

TABLE MS–A
UNMASTERED CARGO HANDLING TECHNOLOGY

- **Integral rapid load/unload/restraint for internal loads.**
- **Automated external load acquisition/discharge.**
- **External cargo handling system for nap-of-the-earth operations.**

CARGO HANDLING

General. The cargo handling subdisciplines, as discussed in this section, are defined in table MS–B.

Certain of the subdiscipline areas within the overall technology of cargo handling are applicable to more than one aircraft; however, due to the rather significant differences in aircraft size and other characteristics, each area must be examined prior to initiating active work to determine whether the effort should be oriented primarily or exclusively to a particular aircraft system, or whether technology could be established or investigated that will be universal in nature.

Interfaces with other cargo handling subdisciplines and major technological disciplines must be considered throughout the program, beginning with the planning stage and continuing through test and qualification of the final hardware item. A primary example is the cargo suspension system, which includes the hoist, tension member, cargo hook, and sling. Although these components each deal with a different technical discipline, compatibility is essential since they connect to form the total subsystem. In addition to their physical interface, their design must include allowances for flight loads, environmental effects, handling and storage, and the structural interface with the airframe. It is also likely that the cargo suspension system will contain power and signal sources for sensors and actuators that will be required for payload stabilization, payload acquisition, and precision hover subsystems. The payload stabilization system is an example of a subdiscipline that interfaces with both the cargo suspension system and the aircraft. Payload motions will be detected by sensors, from which the information will be electronically processed and fed into the aircraft flight controls or active stabilization mechanisms, or a combination of both. The interface, in this case, is therefore very critical.

Figure MS–1 lists the various cargo handling subdisciplines and provides a matrix of interaction between these subdisciplines and related technologies.

TABLE MS–B
CARGO HANDLING SUBDISCIPLINE DESCRIPTION

SUBDISCIPLINE	DESCRIPTION
VEHICLE PERFORMANCE	• Pertains to the means by which overall aircraft systems performance can be improved in conducting tactical/logistical supply and resupply missions. These means include: coupled load analyses for improved stabilization systems; all weather day/night capability, aircraft system compatability with internal/external loads for conventional and noe operations.
PAYLOAD/ACQUISITION DELIVERY	• Pertains to the means for improving mission effectiveness by providing payload acquisition/delivery by helicopters with minimum reliance on ground support systems.

SUBDISCIPLINE AREA	RELATED TECHNOLOGIES					
	AERO DYNAMICS	STRUCTURES AND MATERIALS	DYNAMICS	CONTROL	HUMAN FACTORS	R & M
CARGO SLINGS		x			x	x
CARGO HOISTS		x			x	x
TENSION MEMBERS		x				x
NONDESTRUCTIVE TEST		x				
HARD POINT CRITERIA		x				
PAYLOAD STABILIZATION	x		x	x		
PAYLOAD ACQUISITION				x	x	
CONTAINER HANDLING		x		x	x	
PALLETS AND GONDOLAS		x				
PODS	x	x			x	
CARGO HOOK		x				x
PAYLOAD READOUT	x					
INTERNAL RESTRAINT		x			x	x
CARGO COMPARTMENT CRITERIA		x			x	

Figure MS–1. Technology/subdiscipline interface.

The expected technology improvements for each mission system must interface with the IOC date of the using aircraft. The demonstration of applicable technologies for subdiscipline areas that would become part of the aircraft should, if possible, occur from 4 to 6 years prior to the IOC date. In the case of the external cargo handling system, technology that would improve the effectiveness of the mission system can be productively applied throughout the life cycle of the system; however, there are items that would normally be an integral part of the aircraft, such as payload stabilization subsystems and cargo hooks.

Performance. In the movement by helicopter of men, supplies, and equipment, effective performance of assigned missions is a function of the interacting effects of flight, payload, and operating environment. The correct assessment of generated forces and the influences on each of these elements is essential to setting operational limits, providing data for tradeoff analyses, and establishing balanced design criteria for related subsystems.

Cargo Transport in Terrain Flying Environment. In operating and surviving in a high-air-defense-threat environment, Army helicopters must conduct tactical and resupply missions at altitudes below the level of enemy detection. To enable Army pilots to perform terrain flying missions, current and future helicopters must be provided with new systems, equipment, and techniques that are responsive to the special requirements of such a mission. To avoid detection and engagement by enemy air defense weapons, the pilot must fly at an altitude below 200 ft AGL, maintaining constant altitude and airspeed. If the tactical situation demands flight during instrument meteorological conditions, the helicopters will be flown at or below 200 ft AGL until arriving at the division instrumented airfield, where an instrument letdown will be performed. Upon departing the division rear, the helicopter should not be flown higher than 50 ft above the highest obstacle along the flight path. Initial efforts will be directed toward identification of best technical approaches for achieving the desired capabilities.

Under some conditions of terrain flying, helicopter transport of supplies and equipment will, be performed with payloads carried internally. Ground time for loading and unloading is a critical element of the operation, having a direct relationship to the aircraft's vulnerability, survivability, and productivity. To ensure the success of transport missions involving acquisition and disposal requires the use of internal restraint systems capable of rapid, easy installation and removal. By necessity, such restraint systems should have a low-weight-to-strength ratio, yet have sufficient structural integrity to react to flight dynamic loads.

Development of viable, lightweight internal cargo restraint systems requires reliable and pertinent criteria for rotary-winged aircraft. Current criteria are based upon extrapolated fixed-wing aircraft data.

A program to develop the needed internal restraint reactive load criteria and advanced conceptual restraint systems design should be formulated, based upon the new criteria.

Many types of loads, by virtue of size and weight, will be carried as an externally suspended load. For this type of mission, safety and survivability requires a number of essential capabilities not currently provided in Army helicopters. Typically, these include the ability to minimize separation between the aircraft and the suspended load; positive information to the flight crews relative to obstacles along the flight path; and effective visual augmentation to permit day/night operations.

External Payload Slings. Operational slings evolved from equipment and materials intended for other uses. This has resulted in a high incidence of sling failures, causing a significant dollar loss due to dropped payloads. Lack of design criteria has resulted in progressive downgrading of helicopter rated load to less than one-half of the safe working strength that would be needed to use the lift capability of the CH-47 and the CH-54. Slings are being developed that will match the capability of current and near-term cargo helicopters. Current technology does not, however, permit the degree of weight and drag reduction that will be possible with advanced materials technology. In addition, recent studies have shown no reliable method for determining the safe working strength of sling legs made of materials other than metal. Future efforts in sling technology can therefore be directed toward improvement of reliability, reduction of weight, reduction in aerodynamic drag, and development of a method of nondestructive testing.

Current sling technology for externally transported payloads does not address itself to rapid load acquisition in a high air-defense environment. A family of external cargo slings has been developed, and plans for developmental and operational testing are in preparation. Although these slings provide for dynamic flight payload capability from 6000 to 25,000 lb, problem areas in rapid load acquisition or single disposal of multidestination of combined payloads have not been resolved. Also, optimum strength-to-weight ratios and maximum tension member flexibility have not been achieved.

An on-going research program is required to improve the technology for externally transported payloads in the areas of:

- Safer and reduced acquisition times.
- Individual disposal of multidestination distribution for grouped payloads.

Cargo Hoists. The CH-54 is the only current helicopter with a primary cargo hook mounted on a hoist. Smaller hoists are also used in other helicopters for personnel rescue and handling of smaller cargo items. Recent investigations have shown that a pneumatic hoist drive has reliability and survivability characteristics superior to the hydraulic drives previously used. The primary deficiencies, due to the limitations of current technology, are slow cable speed and high weight. It is planned to direct future efforts toward these areas, while pointing also to improved reliability.

Tension Members. Improvement is needed in materials technology to reduce the weight of tension members. Tension members must be capable of being wound on the hoist drum, have high strength-to-weight ratios, and usually have provisions for transmitting power (electric hydraulic, or pneumatic) for control and operation of the cargo hook and other devices.

Aircraft Hard-Point Criteria. A study has recently been completed that specifies hard-point criteria for current aircraft. Because of the development of new aircraft with differing flight envelopes, a continuous updating should be accomplished to ensure applicability to the new aircraft.

External Load Stabilization. Multipoint suspension and automatic flight control systems are expected to increase allowable speeds from the current 60-80 knots to 100-120 knots by 1980. There is the possibility of a catastrophic failure if one cable breaks on a multipoint suspension system. Consequently, fail-safe and redundant design must be incorporated in a multipoint suspension system. The objective is to achieve 150 knots with the most adverse load in the 1985-95 timeframe.

Current effort is directed toward further developing the active arm external load stabilization system (AAELSS) to a point where the performance of the system may be evaluated and compared to other active and passive stabilization systems. Results of previous flight tests demonstrated that the AAELSS will substantially damp pendular and yaw oscillations of an externally slung load. The AAELSS will offer an alternate system for conventional suspension arrangements and will be applicable to any cargo helicopter with two-point suspension system.

Current techniques for suspending loads from the helicopters in flight may result in the loads assuming attitudes and exhibiting motions that can be attributed to the aerodynamic characteristics of the load. Future generations of transport helicopters will have broader performance envelopes relative to both speed and load-carrying capabilities. Investigations are underway to define the aerodynamic characteristics of typical payloads and to test experimental candidate concepts. There are, however, significant gaps with respect to the adequacy of the concepts.

AD-A035 334 ARMY AVIATION SYSTEMS COMMAND ST LOUIS MO F/G 1/3

ARMY AVIATION RDT AND E PLAN.(U)

OCT 76

UNCLASSIFIED NL

3 OF 4

AD

A035334

OF 4

5334

Automatic Load Acquisition. The productivity of a cargo transport helicopter carrying loads externally is strongly influenced by the time required to acquire and place the load (see figure MS–2). Significant segments of loads to be transported by helicopters will be the handling of containers from ships as well as from land transporters, this time element is critical. Hover time also has a major influence on the fuel consumption. Current practice for the pickup of external payloads is for a ground crewman to manually attach the cargo sling to the hook of the hovering helicopter. Since he must stand directly under the helicopter (and frequently on top of the payload), it is an extremely hazardous operation. Further, the effectiveness of higher cruise speeds can be partially negated by excessive hover times at the payload pickup and release points. Increases in both size and payload of helicopters will require larger capacity sling assemblies, the weight of which is likely to make manual hookup impossible. Technology advancement is therefore required to develop devices and procedures for automatic hookup of external payloads requiring a minimum of prior preparation and no manual attachment.

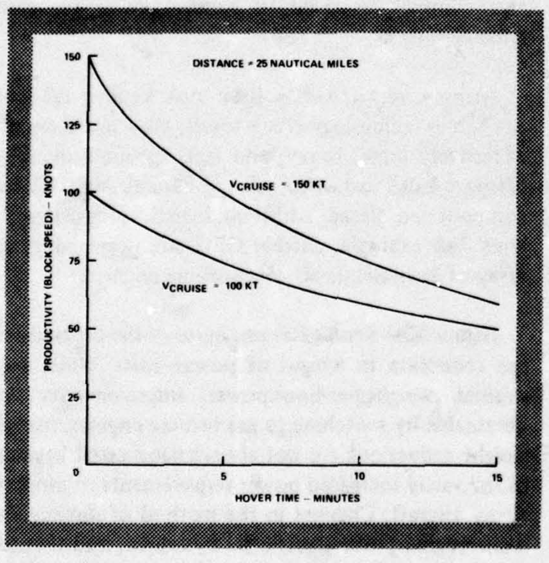


Figure MS–2. Productivity versus hover time and speed.

Container Handling Devices. A first generation helicopter container adapter for Mil-Van containers (8 ft by 8 ft by 20 ft) was fabricated and demonstrated with the CH-54 and the CH-47 helicopters. The usefulness and feasibility of this device was established. This device will use current technology and will therefore be less than optimal during the next 20-year timeframe. In addition, requirements are being prepared for adapters to transport containers up to 40 ft long. To ensure maximum productivity of the helicopters with which these adapters will be used, it will be necessary to develop methods for lighter weight structures, improved mechanization, and simpler operation. A continuing effort is being made to achieve the highest possible reliability at minimum cost.

Pallets and Gondolas. Pallets and gondolas will be used to carry bulk supplies and other items that do not lend themselves for transport by direct attachment of slings. Emphasis is being placed on configurations adaptable for use on various size payloads. Investigations are planned to build prototypes of externally suspended cargo gondolas and evaluate them through flight testing on several Army cargo helicopters.

Cargo Hook Technology. Helicopter cargo hooks require technology advancement to provide acceptable reliability. Dropped payloads due to inadvertent hook release have resulted in a significant dollar loss. In addition, the poor hook reliability is a safety hazard. Work should be directed both to hook configuration and operating controls.

Inflight Payload Readout Methods. Aerodynamic loads on the payload due to downwash and maneuvers can add significantly to the actual load suspended beneath a helicopter. In addition, the actual weight of the payload is frequently unknown. The aerodynamic loading can be attenuated by modifying the distance between the helicopter and the payload. On hoist-equipped helicopters, this can easily be done in flight. The development of advanced technology flight payload readout devices will permit continuous monitoring of the payload weight. This will provide information to the pilot on which he can base the appropriate corrections to the flight path or payload suspension position for minimizing the total load carried by the helicopter.

Internal Restraint Devices. To provide maximum safety under both flight and crash conditions, improved methods for securing internal cargo are required. Load limiting devices have been tested but have not yet been developed for Army aircraft. Improved techniques for cargo tiedown are required to ensure that advanced technology aircraft will not be handicapped by having to use outmoded cargo tiedown methods. Internal restraint devices are also

discussed from a crash safety standpoint, in the Safety and Survivability section.

Cargo Delivery Under IFR Conditions. Specialized areas of research must be integrated so that the resulting technology may be used in optimizing cargo delivery by Army cargo helicopters under IFR conditions. Research has been accomplished, to some degree, in external load stabilization, automatic external acquisitions, helicopter guidance systems, precision hover systems, low-light-level visual augmentation systems, and other related areas. Army cargo helicopters must achieve, through integration of this technology, the capability to locate, acquire, and discharge cargo under cover of darkness and IFR conditions.

GROUND SUPPORT EQUIPMENT

GENERAL

Aviation Ground Support Equipment (GSE) includes a wide range of equipment required to support the operations and maintenance of Army aircraft in the field. The type of equipment varies from complex electronic test equipment to simple maintenance platforms. Consequently, this section does not address a single technology but presents plans for synthesis of numerous technology efforts, primarily by other commodity commands and laboratories, to meet the current and future GSE needs of Army aircraft. Although the basic justification for R&D in the GSE area is in support of the mission systems described in this Plan, the bulk of AVSCOM-funded effort in this area is in response to separately approved development requirements documents for specific end-items of GSE. Studies of the equipment needs of future aircraft or deficiencies in current equipment are the driving forces for R&D efforts.

The GSE area is divided into five functional subareas: ground power units, aircraft servicing equipment, test and diagnostic equipment, ground handling equipment, and maintenance facilities. Some multipurpose equipment can satisfy requirements in more than one subarea (see chart MS–II, located at the end of this section).

The near-term objectives for GSE are documented by draft and approved requirements documents and GSE voids as related by aircraft Program Managers. Developments under these objectives are designed to support the existing fleet of Army aircraft and those currently in development with special emphasis on the AAH and UTTAS.

Peculiar items of support equipment must be identified early in the development program so that equipment will be available to support the aircraft during its test and evaluation phase. It is probable that this new equipment will incorporate the technological advancements that are available at the time rather than requiring new technology development.

GROUND POWER UNITS

This subarea encompasses all equipment required to supply power directly to the aircraft in support of operation (emergency ground start or checkout) or maintenance of Army aircraft in the field. Although Army aircraft have a design objective of being totally self-sufficient, and most new aircraft have on-board auxiliary power units, a need will remain for an emergency backup of these systems and for separate GPUs to support extended maintenance operations. Excluded from this subarea are standard generators and compressors used to supply power to maintenance shops.

Army aircraft GPUs have not kept pace with advancing technology. As a result, they are generally excessively large, heavy, and lack adequate mobility off paved surfaces. Also, a lack of standardization has compounded already difficult logistic support problems. For example, current GPUs are powered by an array of gasoline, diesel, and turbine engines.

Figure MS–3 indicates one state-of-the-art trend in the reduction in weight of power units. While substantial weight-per-horsepower improvements are obtainable by switching to gas turbine engines, overall weight reductions are not always substantial because of the vastly increased power requirements of modern Army aircraft. Changes in the method of starting the main engine from electric to hydraulic, and then to pneumatic, have caused a wide variance of power requirement. In general the anticipated trend will be a reduction in 28-Vdc power requirements with a resultant increase in 120/208-V, 400-Hz, ac power needs. GSE producing pneumatic power is needed for AAH fire control electronics cooling during maintenance, and for emergency engine starting. Simultaneous GSE hydraulic power is needed during emergency starts and must be compatible with UTTAS and AAH hydraulic systems.

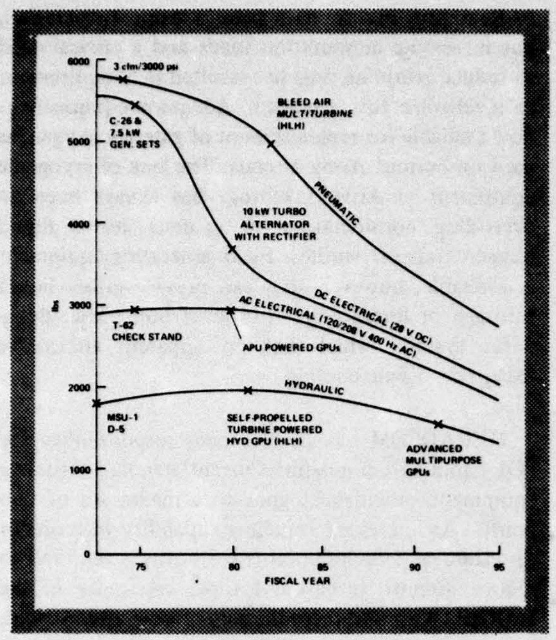


Figure MS–3. Cumulative total GPU weights.

In addition to responding to new or increased power requirements at reduced weights, R&D effort is required to significantly improve the GPU ground mobility for rough terrain operational capability, and air mobility improvements to provide rapid GPU movement to new areas by aircraft organic to the using organizations. Also, standardization on proven military designs is required to improve the logistical support aspects of these units.

A major impediment to achieving the objectives in this subarea has not been insufficient technology, but the lack of firm development requirements. Early development efforts to turbinize GSE were suspended as a result of a change in philosophy from multipurpose GPUs to lightweight, single purpose units for electric, hydraulic, and pneumatic power. Short-term improvement goals are to optimize concepts for and develop a new turbine-powered multipurpose GPU to provide adequate electrical, pneumatic and hydraulic outputs which is highly mobile in rough terrain conditions.

The DOD Project Manager for Mobile Electric Power through MERADCOM has responsibility for development of the DOD Standard Family of Mobile Electric Power Generating Sources, along with the Army family of military standard engines. Currently in development at MERADCOM are turbinized 10 and 30 kW 30/60 Hz ac versions of the 10 kW GPU to be developed and evaluated. The 10 kW 28 V dc GPU will be applicable to most current-fleet Army aircraft. The 50/60 Hz GPUs are designed to be used as general utility power supplies. Guidelines for combat zone usage dictate development of higher degrees of GPU air and ground mobility coupled with output power characteristics compatible with the developmental aircraft subsystems. Other possible future applications are shown on figure MS–4. In general, application of standard generator sets for use as aircraft GPUs involves incorporation of chassis, integral fuel tanks, and cable storage provisions. Consideration should also be given to improving ground mobility. To achieve commonality, a multipurpose vehicle could be developed capable of powering various single or combination ground power or servicing modules.

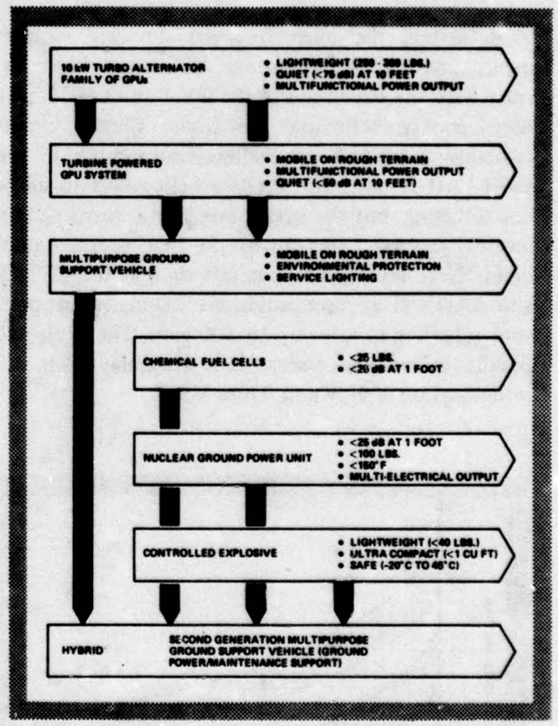


Figure MS–4. Ground power units.

AIRCRAFT SERVICING EQUIPMENT

Servicing equipment includes GSE required to replenish the aircraft with POL, ammunition, oxygen, and other consumables. The equipment needed to clean, de-ice, or preheat the aircraft at the flight line is also included. Good servicing equipment is required to allow rapid turnaround times for the aircraft. A

program for establishing better aircraft servicing equipment is shown in figure MS–5.

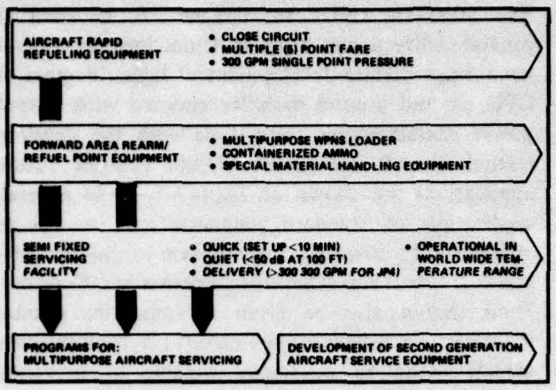


Figure MS–5. Aircraft servicing equipment.

Refueling, the most frequent servicing requirement, deserves first attention. All current Army aircraft with the exception of the OV-1 and CH-54 have only gravity refueling provisions. Closed circuit refueling provisions are being incorporated in the UH-1, AH-1, and OH-58/OH-6 helicopters to allow hot refueling, but the actual rate is still restricted by internal crossover lines or by the POL supply equipment. New development aircraft such as the UTTAS and AAH will all have provisions for singlepoint pressure refueling at rates up to 300 gpm. The projected payoff in reduced service time resulting from this refueling rate is shown in figure MS–6.

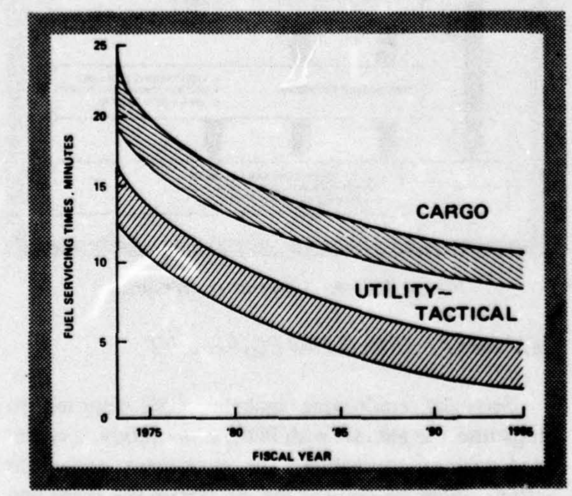


Figure MS–6. Projected aircraft servicing time (single-point refueling).

Rearming has to date been a manual operation, but increasing ammunition loads and a critical need to reduce rearming time has resulted in a requirement to mechanize this operation. Adequate equipment is now available for replenishment of gaseous oxygen, as used on current Army aircraft. The lack of cryogenic equipment in Army inventory has always been an overriding consideration in gaseous versus liquid oxygen tradeoff studies. Field generating equipment is available, however, that can provide either liquid nitrogen or liquid oxygen to an airborne laser designator system, which has no apparent alternative except cryogenic cooling.

MERADCOM has development responsibility for POL-handling equipment. Current standard refueling equipment provides 50 gpm to a maximum of two points. An increased refueling capability in terms of flow rate or refueling points (or both) is required to reduce aircraft turnaround time, especially in the FARRP. With the introduction of new aircraft with larger fuel capability and higher acceptance rates, a definite need exists to exploit this capability with highly mobile pumping, filteration, container/storage equipment.

The current concept of carrying the fuel in a tanker vehicle from a tank farm to the aircraft appears to require revision. One alternative is the use of semifixed refueling points. Disadvantages of this system are the requirements for high-pressure, high-capacity pumps, and the need to layout and take up the distribution system. A second alternative is the use of pumper vehicles similar to those at large airports, but capable of rough terrain operations. The vehicle needs to carry only the pump and sufficient flexible hose to connect from a central tank to the aircraft. This reduces the vehicle weight and allows greater off-ramp mobility. A third alternative is the use of encapsuled, replaceable fuel pods, which envisions replacing an empty tank (or pod) with a full tank rather than pumping fuel into the tank.

Current ongoing programs by AVSCOM include engineering development of an Aircraft Weapons Handling Vehicle and a Cleaning and De-Icing System (CDS) for Army Aircraft Maintenance. The weapons-handling vehicle is intended for both the FARRP and in the more conventional rearming areas. The proposed vehicle is very similar to conventional bomb loaders used by the Navy and Air Force, except that soft and rough terrain mobility would be vastly improved.

The CDS is a self-contained, high-pressure spray cleaner designed to clean and de-ice Army aircraft. The unit is built around commercially available high-pressure, hot-water cleaning equipment mounted on a four-wheeled trailer with self-sufficiency features that allow operations out of austere sites. These features include storage tanks for solvent, detergent solution, and rinse water; a suction pump for drawing water from available sources; and mounting provisions for a standard generator set. The military potential of this equipment has been demonstrated through a test of a breadboard model. Additional prototypes have been procured to complete the development acceptance testing. After adoption for aviation use, plans include expanding the basis of issue for other Army applications.

TEST AND DIAGNOSTIC EQUIPMENT

This subarea encompasses all equipment being developed for inspection, testing, and checkout of Army aircraft. To reduce the high annual maintenance costs, equipment must be developed to accurately and reliably monitor aircraft systems, and detect and diagnose malfunctions early enough that corrections can be made on a timely basis. By reducing inspection times, incorrect diagnoses, unwarranted removals, high spare parts consumption, secondary damage, and by going to on-condition component replacement, aircraft availability rates will increase and major cost savings result. Figure MS–7 identifies anticipated cost savings for a typical aircraft currently in development.

A three-year program on the UH-1H to collect and analyze component failure data and to design, fabricate, and test prototype Automatic Inspection Diagnostic and Prognostic Systems on the UH-1H aircraft is nearing completion. The basic objective of this effort is to test several prototype systems in an operational environment to demonstrate both system and cost effectiveness. The resultant system will then be considered for any necessary modification and adaptation to future Army aircraft.

Based on a recent study, the most cost-effective approach for diagnostic equipment requires that most data be acquired, processed, and partially analyzed in flight. The complete analysis is performed with ground equipment subsequent to aircraft landing. This approach will enable the system to display malfunctions of flight-critical components to the pilot for immediate corrective action. Such an approach requires that each aircraft be equipped with an inflight analysis and display system. During the AIDAPS development program, this concept (plus the following two alternate approaches) will be evaluated. Alternate 1 requires that data be acquired and processed in flight but completely analyzed in a ground unit. This would enable most of the complex computer logic to be built into the ground module and shared among a number of aircraft. Alternate 2, the "maintenance ride" concept, requires that a total diagnostic system be taken for a test ride on a periodic basis or whenever a potential problem has been encountered. Except for sensors and related wiring bundles, the electronic hardware is readily removed and replaced. This approach would enable a complete system to be shared among many aircraft. These concepts will provide for a flexible program from the standpoints of economy and simplicity of aircraft equipment and operation.

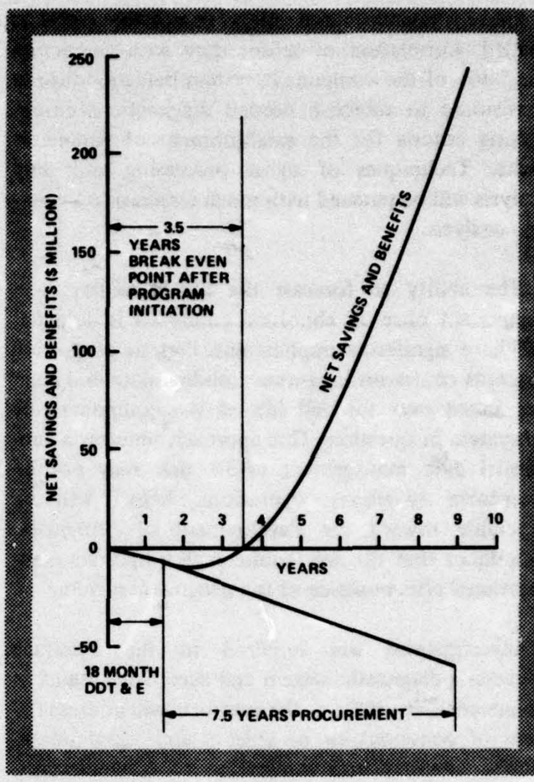


Figure MS-7. AIDAPS Hybrid I system time-phased program costs, savings and benefits.

Continuing efforts will be conducted in supporting technology areas to solve the deficiencies that exist in the diagnostic area. Efforts will be put forth to advance sensor technology to provide the rugged,

accurate, reliable, and flight-compatible sensors needed. Correlation of sensor data with the actual condition of the component/system being monitored is required to establish needed diagnostic decision-making criteria for the establishment of parameter limits. Techniques of signal processing and data analysis will be pursued with much emphasis on vibration analysis.

The ability to forecast the life remaining in a component once an abnormal condition is detected will have significant implications. Present prognostic concepts center on long-term trending data and analysis taken over the full life of the component or subsystem in question. This approach requires a substantial data management effort that may not be acceptable to Army operations. Effort will be expended toward the development of prognostic techniques that do not require such a rigorous computational effort outside of the diagnostic system.

Investigations are required in the interface between a diagnostic system and such other items as engine cockpit displays. These efforts will address the areas of commonality of sensors and signal conditioning circuitry and integration of crew displays. Additional effort is required to study and develop the capability of the AIDAPS ground unit to handle automatically The Army Maintenance Management System (TAMMS) data, thereby eliminating many forms and manual reporting man-hours now performed at several levels of maintenance.

Figure MS–8 depicts the program for developing advanced prognostic systems. An exploratory development program will be conducted for approximately the next 5 years under the direction of ARMCOM to address those aspects of AIDAPS that have multi-commodity impact. Investigations will be conducted into vibration signal analysis, hydraulic, pneumatic, electrical and mechanical stimuli loading, accessibility criteria, system component packaging and man/machine interface. These hardware efforts will be complimented by software tasks in the areas of test procedure language, automatic test equipment language, and automatic program generation. The breadboarding or testing of analytical techniques will be conducted either in the laboratory or by experimental prototypes to determine the feasibility of the selected approaches and to analyze these approaches as they relate to the subsystems responsibility within each commodity command. The basic goal is to have the modular functional capability to test and diagnose all subsystems within each commodity command and at all levels of maintenance. AVSCOM and AMRDL will participate in this program insofar as it addresses Army aviation. This exploratory development will culminate in the demonstration of the technical feasibility and the initiation of engineering development. The ultimate goal of this program is the fielding of multipurpose automatic inspection diagnostic equipment, applicable to all commodities in the 1985 timeframe.

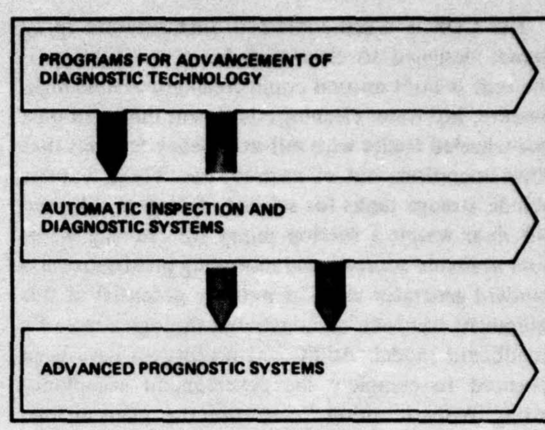


Figure MS–8. Test and diagnostic equipment.

GROUND HANDLING EQUIPMENT

This functional area includes all equipment required to move, jack, or secure Army aircraft on the ground. Also included are GSE items required to handle aircraft components such as hoists, slings, and transport trailers.

Current aircraft ground handling equipment is not designed to support aircraft in forward austere sites. Skid-mounted aircraft use small ground handling wheels with high ground pressure, making movement on soft or uneven terrain virtually impossible. Lacking a standard towing vehicle, conventional military trucks are used to relocate aircraft. This often results in damage to the aircraft or the vehicle. Equipment used to remove components ranges from small, fragile davit cranes to huge 5-ton wreckers. Although the M819 5-ton wrecker has vast reserve lifting and towing capacity, it is not air transportable with current Army helicopters.

Development is required in this area to provide a ground movement system for the aircraft capable of supporting both operations and maintenance. Much

attention has been given to aircraft safety and survivability by ballistic protection, crashworthy fuel systems, and electronic warfare self-protection systems while airborne; however, very little attention has been given to the much longer periods when the aircraft is subject to enemy action while it is on the ground. By providing an adequate ground movement system capable of operating off prepared surfaces and in rough terrain, aircraft can be moved into and under natural foliage for dispersion and concealment. If revetments are available, the helicopter can be towed in, instead of hovering. In this way the frequency of rotor strikes can be greatly reduced. Concept formulation efforts are in progress to define a system which will provide a significant increase in air and ground mobility and operation without degradation of the aircraft inherent mission reaction time.

Ground handling equipment used to support maintenance (including hoists, slings, and transport trailers) must be designed for efficient operation in forward areas without damaging expensive aircraft components. All equipment, especially at the lower levels of maintenance, must be airmobile and compatible with airmobile maintenance shelters. The only approved requirements document is for an airmobile, self-propelled crane to support maintenance of all Army aircraft. The current program is for the evaluation of existing mobile hydraulic cranes. Known commercial cranes have sufficient capacity and reach to support maintenance on all Army aircraft, yet they are airmobile by CH-47 and CH-54. These cranes also have vastly improved maneuverability and visibility to enhance safe operations in a maintenance area. The crane will be complemented by the recently developed standard trailer system with appropriate adapters for handling all components.

A detailed ground handling equipment program appropriate for future airmobile systems is shown in figure MS–9.

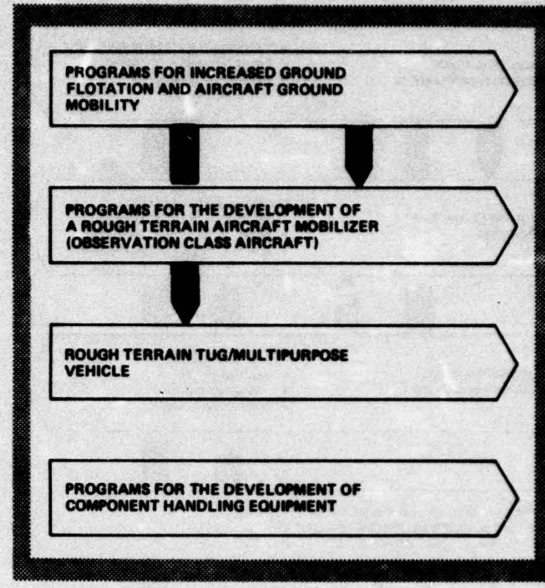


Figure MS–9. Ground handling equipment.

MAINTENANCE FACILITIES

Maintenance facilities include equipment and structures normally connected with fixed airfield or maintenance shops. This subarea, however, is restricted to deployable shelters and equipment. The current aviation maintenance shops for standard DS and GS levels are installed in semitrailer vans. While providing adequate ground mobility, these vans are excessively heavy and in general not compatible with airmobility/air transportability requirements.

Although the Army has for some time had a concept of airmobile maintenance, for all practical purposes all maintenance beyond the organizational level is still restricted to fixed-base facilities. Shelters have been developed to transport tools and shop equipment, but an adequate shop area is still lacking. Also, with the exception of an Ensure tent shelter for UH-1-sized helicopters, Army aviation does not have a portable shelter capable of housing aircraft for maintenance.

The basic objective of R&D in this area is to provide those maintenance facilities required to support a rapid movement of the maintenance base and facilitate aircraft maintenance in remote areas under all environmental conditions. Also to be considered is the problem of blackout conditions at night.

The threats of midintensity conflict introduce new requirements for maintenance facilities. The shelter requirements to support night maintenance on aircraft are currently under study. The programs shown in figure MS–10, supplemented by additional efforts as identified by the above study, could provide adequate maintenance facilities compatible with airmobile maintenance operations.

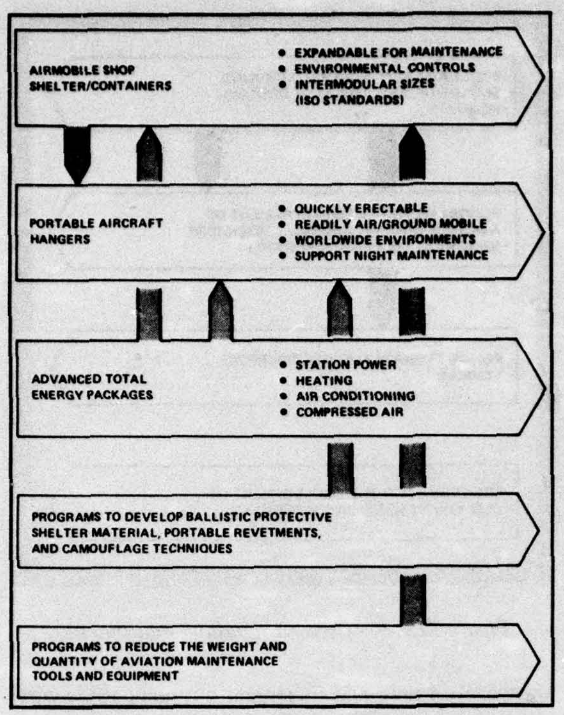


Figure MS–10. Maintenance facilities.

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the cargo handling and ground support equipment efforts controlled by AMRDL. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within an effort as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines within cargo handling and ground support equipment technology can be established from the near-term quantified achievement goals listed in chart MS–I and chart MS–II (AMRDL efforts).

The near-term cargo handling objectives are of two types: improvements in external load carrying devices and improvement in load acquisition and stabilization, while the objectives for GSE is the improvement of ground mobility for helicopters. The program objectives are:

- Achieve a 50% improvement in capabilities for cargo operation in terrain flying conditions.
- Achieve a 50% improvement in helicopter turnaround time during internal loading and unloading operations.
- Achieve a 50% improvement in cargo system component reliability.
- Develop means for automatic load acquisition and cargo placement to eliminate the need for a ground crew.
- Achieve inflight load stabilization improvements by a factor of 3, with resulting improvements in forward speed.
- Develop an all-terrain standard helicopter movement system.

PROGRAM PRIORITIES

General. Table MS–C presents, in a prioritized listing, the AMRDL mission support subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The AMRDL mission support subdisciplines are represented by the major topical areas as discussed below:

- Cargo carrying and handling – pertains to such items as cargo slings, pallets, gondolas, pods, cargo hoists, tension members, cargo hooks, and container handling.
- *Payload acquisition and restraint* – pertains to such items as penants, payload readout, multipoint suspension, automatic cargo acquisition and drop-off, container aerodynamics, and interface with other means of container transportation.
- *Internal loading and restraint* – pertains to such items as cargo/troop accommodations, restraint systems, and ingress and egress.

- *Design criteria* – pertains primarily to system dynamics and vehicle hardpoints.
- *Inspection techniques* – pertains to nondestructive test methods for residual strength of various system components but primarily textile materials.
- *Ground mobility system* – pertains to ground mobility means for covert deployment of helicopters in the forward area.
- *Ground support equipment* – pertains to specialized equipment to service aircraft on the ground.

Vehicle Subsystems. Vehicle subsystems, as related to mission support technology, are categorized as follows:

- External cargo delivery equipment
- Internal cargo delivery equipment
- Ground mobility equipment
- Ground servicing equipment

System Effectiveness. In the area of system effectiveness, the primary impact of mission support is, by definition, mission performance. However, in all mission support areas, life cycle costs, vulnerability, and safety and survivability are on a nearly equal rating with performance.

Priorities. With reference to table MS–C, the mission support subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

Assessment of the priority listing in table MS–C and the near-term objectives indicates the following major thrust areas:

- The development of cargo transport technology with terrain flying capability in adverse weather conditions with the principal emphasis on reduced vulnerability, safety and survivability without degradation of mission capability is a top priority AMRDL thrust.
- A practical solution to the problem of helicopter movement over unimproved surfaces has not been defined. This could be a critical factor in achieving required dispersion and natural concealment in forward areas.
- Performance improvement of aircraft servicing equipment to reduce the turnaround time of aircraft, in particular the attack helicopter is another high priority effort. Exercises conducted by TRADOC Combined Arms Test Activity (formerly MASSTER) has identified some major areas requiring excessive turnaround times. Additional effort is required to

TABLE MS–C
PRIORITIZED MISSION SUPPORT OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Payload acquisition and restraint	I	• External cargo delivery equipment	I	• Mission performance	I
• Cargo carrying and handling	III	• Ground mobility equipment	II	• Life cycle costs	II
				• Vulnerability	III
• Ground mobility system	III	• Ground servicing equipment	III	• Safety and survivability	IV
• Ground support equipment	IV				
• Internal loading and restraint	V	• Internal cargo delivery equipment	IV	• Reliability and maintainability	V
• Design criteria	VI			• Human factors	VI
• Inspection techniques	VII				

provide a satisfactory deployment of the attack helicopter.

LABORATORY PROJECTS IN MISSION SUPPORT

INTRODUCTION

Mission support technological development effort is directed towards exploratory development (6.2), advanced development (6.3), and engineering development (6.4) to increase the knowledge of and to demonstrate advanced technology concepts of mission support equipment for airmobile systems.

Various commodity commands and laboratories are involved in the R&D efforts described in the technological discussion on GSE in this section. However, this program discussion deals with only the projects being performed by AMRDL in the 6.2 and 6.3 categories.

All developmental efforts are conducted by AMRDL Eustis Directorate at Ft. Eustis, Virginia by either in-house efforts or by contract.

DESCRIPTION OF PROJECTS

Mission Support Technology. Project 1F262209AH76-TA VI is an exploratory development effort to develop mission support equipment that will enhance the effectiveness of military operational capabilities of Army aircraft, particularly in the forward area. Principal technology areas are cargo handling and aircraft ground support equipment, cargo transport technology investigations have been expanded to include operation in a high defense threat environment requiring terrain flying capability. Efforts on automatic payload acquisition and stabilization systems will continue. Ground support equipment investigations will emphasize improved aircraft servicing equipment to reduce turnaround times and ground mobility to enhance covert deployment of helicopters in the forward area.

Cargo Handling Equipment. Project 1F263209DB33 is an advanced development effort to demonstrate the potential and to determine the effectiveness of new concepts and designs of cargo handling equipment. Included in this effort is the establishment of the technical feasibility and development of prerequisites necessary for the orderly transition of selected items from exploratory to engineering development. The most promising equipment, subsystems, devices, and/or components, resulting from related exploratory development, will be fabricated for experimental and/or flight and operational testing to verify designs and validate forecasted potentials. This work will support all current and planned Army aircraft whose mission includes transporting cargo and/or personnel. The output of this program will increase aircraft safety, improve cargo handling subsystems, improve reliability, and increase overall mission effectiveness of Army aircraft.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the mission support R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 and 6.3 mission support R&D efforts are shown in table MS–D. Included in the table is the ratio of the mission support efforts to the total 6.2 and 6.3 AMRDL R&D efforts.

TABLE MS–D

AMRDL MISSION SUPPORT TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.2*	1F262209AH76-TA VI	960	6%
6.3	1F263209DB33	300	2%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

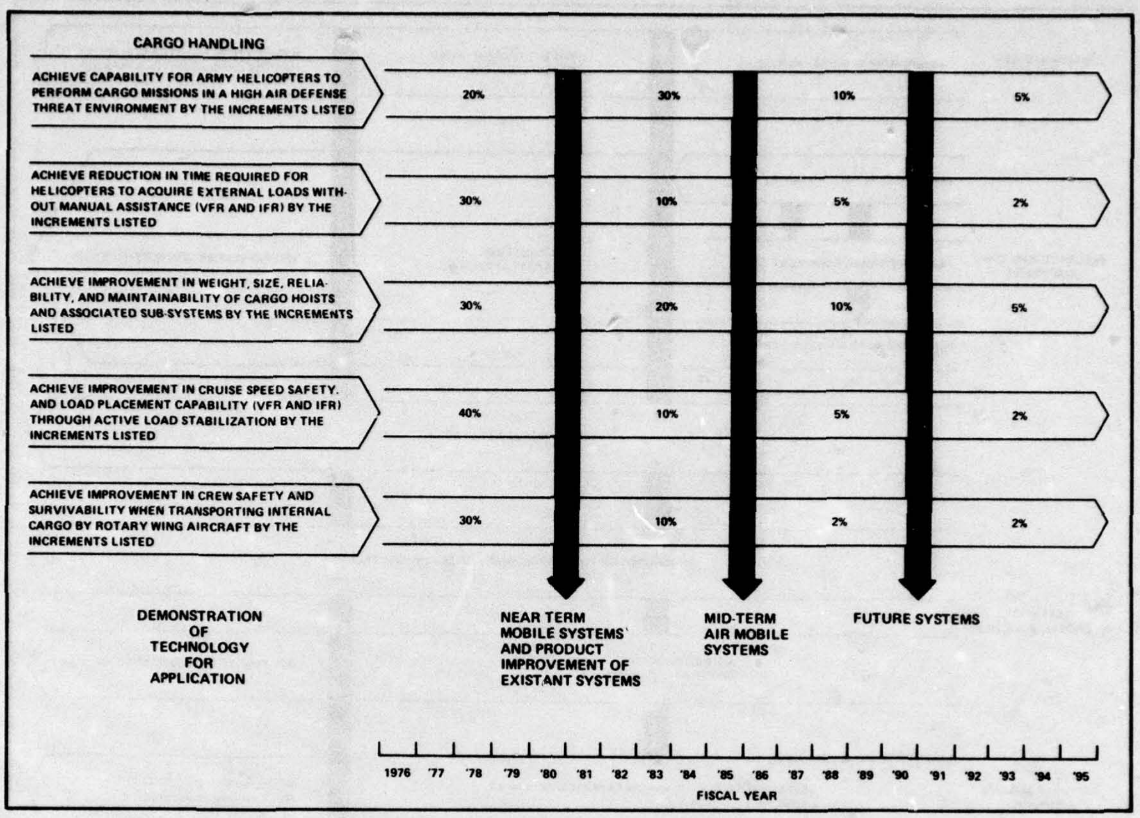


Chart MS–1. Cargo Handling Achievement Goals.

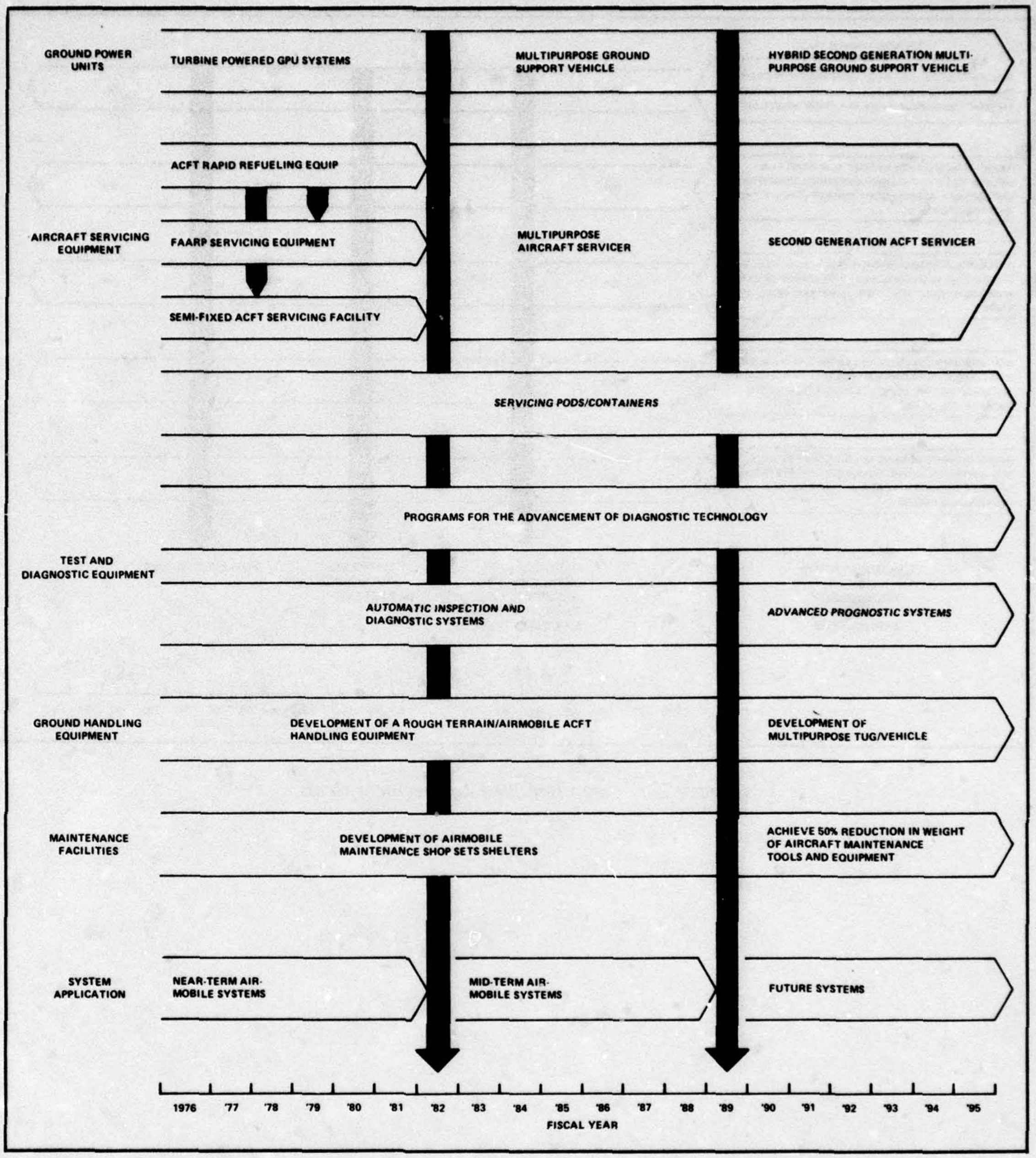


Chart MS–II. GSE Program Objectives Summary.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

SECONDARY POWER SYSTEMS

LANDING GEAR SYSTEMS

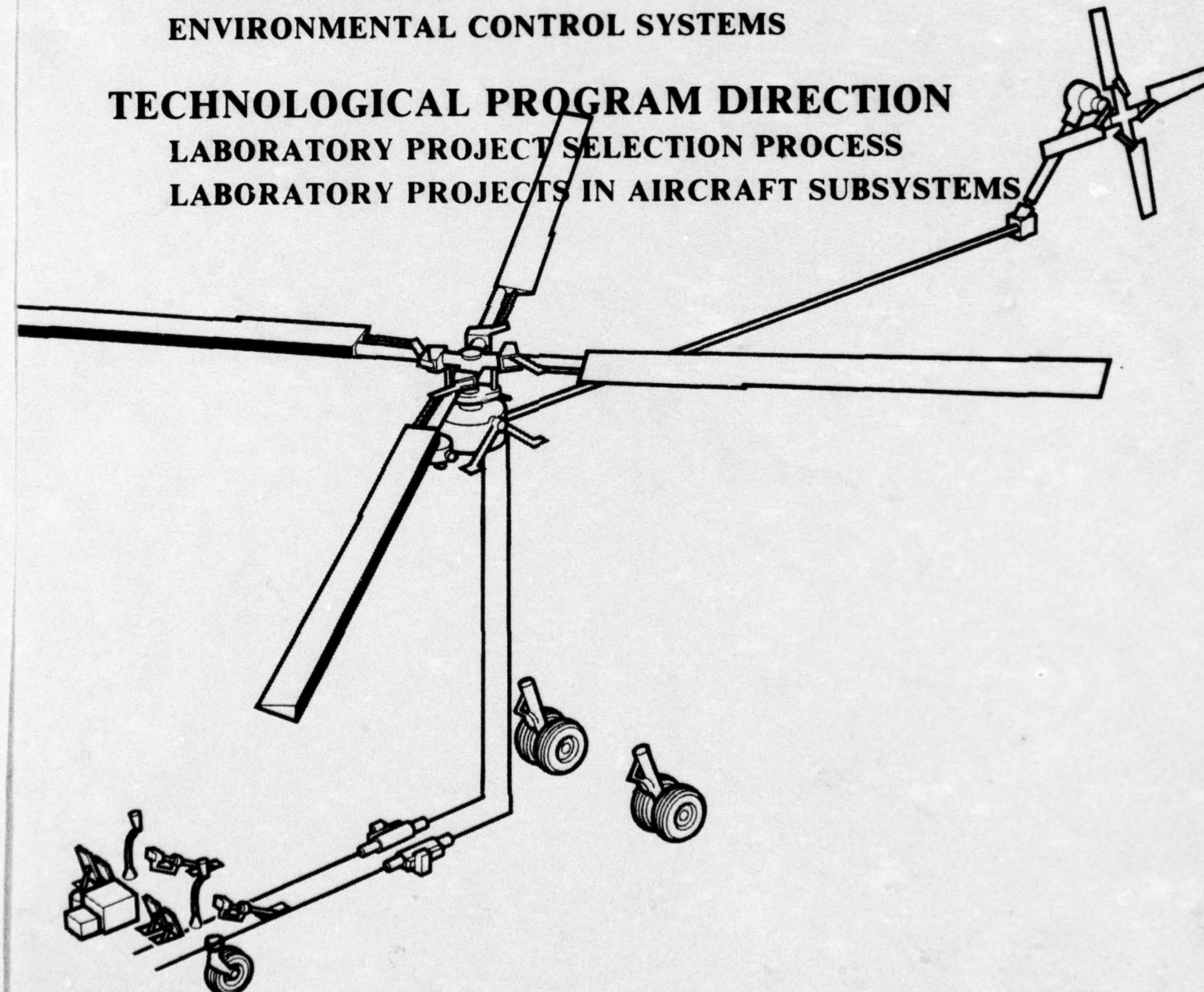
FLIGHT CONTROL SYSTEMS

ENVIRONMENTAL CONTROL SYSTEMS

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS IN AIRCRAFT SUBSYSTEMS



INTRODUCTION

The term subsystems, as applied to Army aircraft and used in this section of the RDT&E Plan, applied to those subsystems of the aircraft that provide the basic power to operate all aircraft systems except for the main lift and thrust (primary power) systems. Not included in this section are electronics, cargo handling, and weaponization.

The aircraft subsystems that have been used on helicopters in the past have, in general, been developed for fixed-wing aircraft. Little or no consideration has been given to the peculiar requirements and environmental conditions encountered by helicopters during the performance of the Army missions. This practice has resulted in low-life components, excessive maintenance, frequent mission aborts, and inability to perform needed missions.

The various mission/performance characteristics of aircraft are not ordinarily significant factors in the subsystem requirements. Thus, the results of an R&D program that has provided a technology advancement in any subsystem can be applied to all future aircraft and, in many cases, to current aircraft. On the other hand, there is little interdependence among most of the subsystems. Technological advancements in one subsystem may be accomplished, although problems remain unresolved in another.

Since a large problem in present aircraft subsystems is low reliability and high maintainability, the programs conducted for improved subsystems will be closely coordinated with the reliability and maintainability R&D activities for maximum use of the information obtained under that program.

The overall R&D efforts related to the aircraft subsystems technology discussed in this section are shown in chart AS–I (located at the end of this section). The application of the technological improvements is keyed to near-term, mid-term, and future systems. However, any improvements could be applied to existing aircraft through PIP programs.

Secondary power systems, landing gear systems, flight control systems, and environmental control systems, with accompanying charts and graphs, are described in more detail in the following subsections with specific goals and programs necessary to provide mission oriented aircraft subsystems.

TECHNOLOGICAL DISCUSSION

SECONDARY POWER SYSTEMS

GENERAL

Secondary power systems include electrical, hydraulic, pneumatic, and mechanical. All of these have one common feature: they are concerned with the conversion of energy from some type of power generation system to perform some necessary function in the operation of the aircraft system. Another common feature is that they are not greatly affected by the performance characteristics of the aircraft.

ELECTRIC POWER

Electric power requirements of Army aircraft have grown through the years, and are expected to grow further. Although the switch from direct current generators to alternating current generators has resulted in weight reductions, areas still remain where significant improvements in weight and efficiency can be realized. The weight of current alternating current generators is 1.5 to 2 lb kva. This should be reduced to 0.5 lb per kva (see figure AS–1). The efficiency of the generator should be increased from the current 85 percent to 95 percent.

Batteries are the most unreliable component in the electrical power system. The current MTBF of

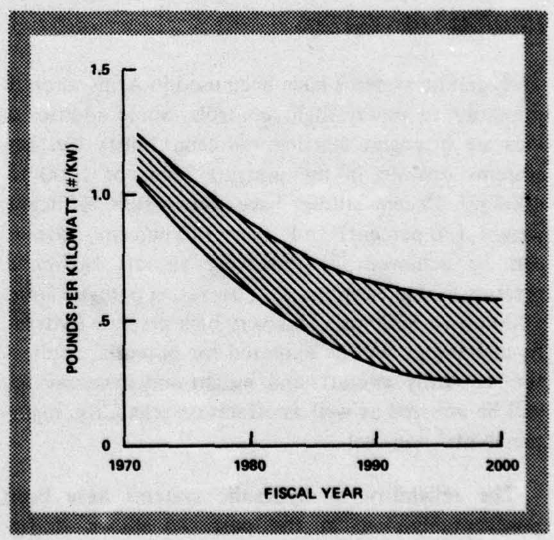


Figure AS–1. Electrical power generator weight goal.

approximately 200 hr can be increased if proper condition monitoring and preservation techniques are developed. The current mean time between unscheduled maintenance actions is now 50 to 100 hr. Advanced technology application should increase this to more than 500 hr and also reduce the weight from 2 lb per amp-hour to less than 1 lb per amp-hour.

The electrical power distribution system has been the source of many problems centered primarily in the connectors and control devices such as relays, switches, contactors, and circuit breakers. Power conductors are heavy. New concepts of power distribution systems should be investigated. There is a potential weight reduction of 50 percent that could result from the incorporation of advanced technology. Typical component/concepts are remote controlled circuit breakers and flat cable, flat conductor wiring, aluminum wiring and matrix interconnected wiring.

Advanced system concepts which should be examined for long term payoffs include high voltage, direct current systems, multiplexing, and fiber optic controls.

In the long term, new sources of electricity such as fuel cells and magnetohydrodynamics (MHD) will become available. The application of these technologies to Army aricraft must be examined to determine the benefits that would be realized. Superconductors may be effectively applied in the near-term period.

HYDRAULIC SYSTEMS

Hydraulic systems have been used in Army aircraft primarily to power flight controls. Some additional uses are in engine starting and cargo hoists. Current systems operate in the pressure range of 1000 to 4000 psi. Recent studies have shown that signficant weight (30 percent) and space (40 percent) savings can be achieved in fixed-wing aircraft hydraulic systems by increasing system operating pressure from 3000 psi to 8000 psi. This very high pressure hydraulic technology will be explored for potential application to Army aircraft, and weight and space savings will be assessed as well as effects on reliability, maintainability, and cost.

The reliability of hydraulic systems have been unacceptably low in the past. As shown in figure AS–2, hydraulic system failures have accounted for a high share of the flight aborts in Army aircraft.

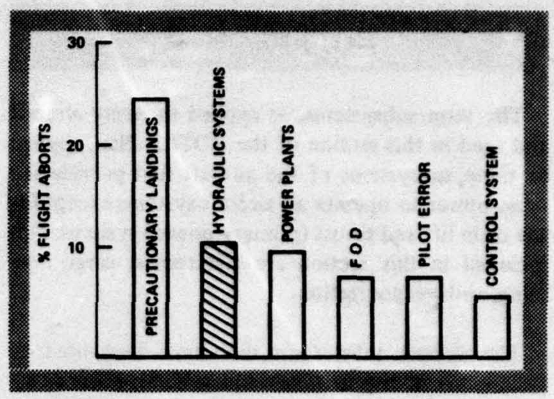


Figure AS–2. Major causes of flight aborts (noncombat)

Current hydraulic pumps create a pressure ripple that produces tubing wear and fatigue problems. The high vibratory environment in helicopters imposes additional stresses in the system components.

As flight control systems become more sophisticated with the adoption of fly-by-wire concepts, the hydraulic power units must be made more reliable. Means must be provided to accomplish this without imposing unacceptable penalties in cost, complexity, and weight.

Hydraulic power systems technology needs improved sealing techniques, high-temperature capability, system distribution methods, and fluids to reduce power requirements and provide increased survivability and reliability. The incorporation of fluidics in the control of hydraulic systems should be expanded.

Contamination monitoring and control must be improved to ensure increased reliability. Achievable reliability goals are shown in figure AS–3.

PNEUMATIC SYSTEMS

Although pneumatic power systems have not been employed to any extent in the past, this trend is expected to change significantly on future Army aircraft. The development of efficient air turbine motors and the exclusive use of gas turbine engines, with their available supply of pneumatic power, makes this type of power more attractive.

Pressurized air starting systems may offer significant weight and performance payoffs at similar cost to electric starting systems for aircraft utilizing advanced technology turbine engines such as to T700.

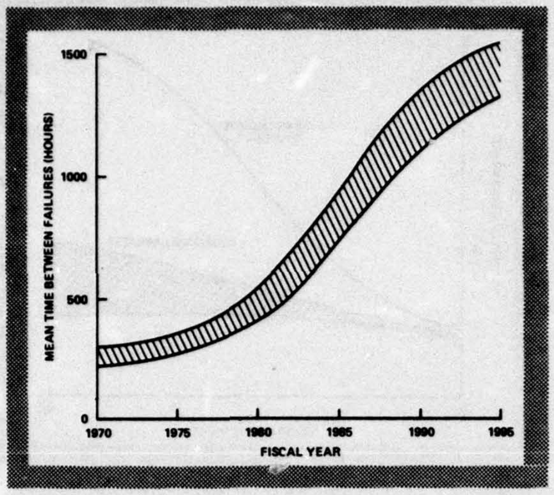


Figure AS–3. Hydraulic system reliability goal.

MECHANICAL SYSTEMS

Regardless of the type of secondary power source, the requirement to transmit, change direction, or couple the power unit to the functional unit will remain. This requirement will probably be performed by some mechanical component such as shafting, push rods, bell cranks, and rod ends. The reliability and vulnerability of these components must be improved to the extent that they will not be the weak link in the chain. The use of composite structures will contribute to the reduction in weight and increased survivability. The development of flexible joints such as elastomeric bearings to replace rod ends and bell crank pivots will significantly improve the reliability.

A relatively new concept that demonstrates considerable potential is a high-speed flywheel that can store energy for intermittent use. The use of high-strength fibers will bring this concept closer to reality. Additional work must be done to determine configurations and applications of this technology. To apply this type of power device to any useful purpose, advanced couplings or clutches must also be developed.

SECONDARY POWER SYSTEM TOPICS SUMMARY

The various research topics pertaining to secondary power system techology can be categorized as listed in table AS–A. Should each of the areas be adopted as an element of unified research program to develop advanced electrical, hydraulic, and pneumatic power systems, the objective goals indicated in chart AS–I could be achieved.

LANDING GEAR SYSTEMS

GENERAL

The ground-mobility requirements of almost all future Army aircraft include operation in the forward

TABLE AS–A
SECONDARY POWER SYSTEM TOPICS SUMMARY

SUBDISCIPLINE	TOPIC
ADVANCED ELECTRICAL SYSTEMS	• Improved generation and transformation devices for weight reduction, reliability and efficiency • Advanced concepts of remote and automatic control devices • Advanced battery systems for improved reliability
ADVANCED HYDRAULIC SYSTEMS	• Improved hydraulic fluids for safety and efficiency • Investigation of hydraulic system materials for improved reliability, efficiency, and weight • Investigation of hydraulic lines, connectors, and seals for improved reliability and decreased maintenance • Investigation of hydraulic system operating pressure for reduced weight and space
PNEUMATIC POWER SYSTEMS	• Investigation of pneumatic motors, ducts, and controls for decreased weight and maintenance and increased survivability

areas from unprepared sites. The exception which might not require high-flotation gear and might be expected to operate only from corps area landing fields would be for some intelligence missions. Recent experience has demonstrated that operations have been restricted as a result of inadequate flotation and ground-handling capability.

Techniques must be developed to increase ground mobility without imposing unacceptable penalties in weight, speed, or handling. Advancements in this technology are particularly applicable to those aircraft that are normally moved on the ground for servicing, maintenance, or concealment, such as AAH and UTTAS.

The weight of landing gears as a percentage of gross weight would increase unacceptably if simple add-on approaches were used. The use of readily attached or detached ground support equipment can significantly widen the spectrum of approaches, such as high flotation tires or air cushion concepts to provide the necessary ground mobility far beyond that inherent in the aircraft landing gear. Skid-mounted helicopters, such as UH–1, must be provided with a means for ground movement over unprepared surfaces.

Landing gears on Army aircraft are designed to withstand sink speeds commensurate with the operational requirements of the aircraft. When subjected to crash conditions, they offer little protection to the occupants. Although criteria for crash survivable structures have been established, means for meeting these criteria have not been fully explored. This is particularly true if new concepts for meeting ground-mobility requirements are adopted.

Sought-after improvements in advanced technology landing gear that will permit aircraft to operate from any surface are shown in figure AS–4. As a reference, the figure shows also the projected weight penalty anticipated in applying current design practice to solve the newer, more stringent criteria.

LANDING GEAR TOPICS SUMMARY

The two basic areas of research in this area are:

- Investigation of new techniques to achieve increased ground mobility.

- Development of crash-survivable, high-flotation landing gear.

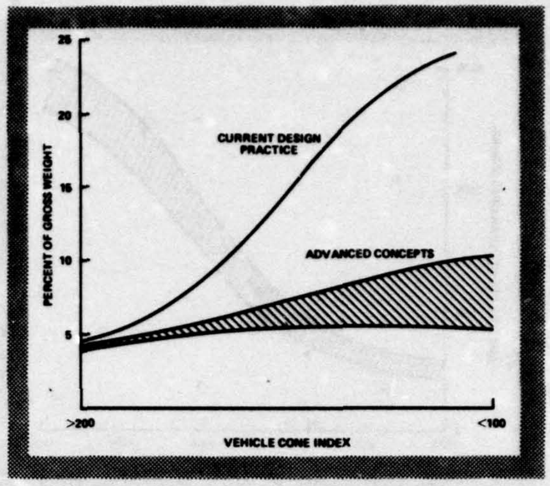


Figure AS–4. Landing gear weight improvement goals.

Should each of the areas be adopted as an element of a unified research program, the objective goals for landing gear development indicated in chart AS–I could be achieved.

FLIGHT CONTROL SYSTEMS

GENERAL

The flight control system is composed of all those elements from the pilot's controls to the aerodynamic control surfaces. These elements (or subdisciplines) can be electronic, fluidic, or mechanical. Also included are those elements that furnish inputs to the control system during normal flight.

The criticality of the flight control system is obvious. As aircraft grow larger and are required to perform relatively violent maneuvers, pilots are unable to provide sufficient power to control the aircraft. Thus, controls with 100 percent power boost are required. The response characteristics of the flight control system are determined by the stability, control, and handling qualities requirements of the particular aircraft system, and developments in the aircraft subsystem relate intimately to the technological advances achieved in these disciplines.

The primary problem in flight control systems has been their low reliability. The Mean Time Between Unscheduled Maintenance (MTBUM) has been approximately 25 hr. With the more complex requirements on advanced aircraft systems, this figure would

be expected to deteriorate. It is anticipated that an advancement of technology and proper design for maintenance could achieve an MTBUM of 400 to 500 hr, and at the same time reduce the time required to perform the maintenance. See figure AS–5 for the sought-after improvement trends over the next 20-year period.

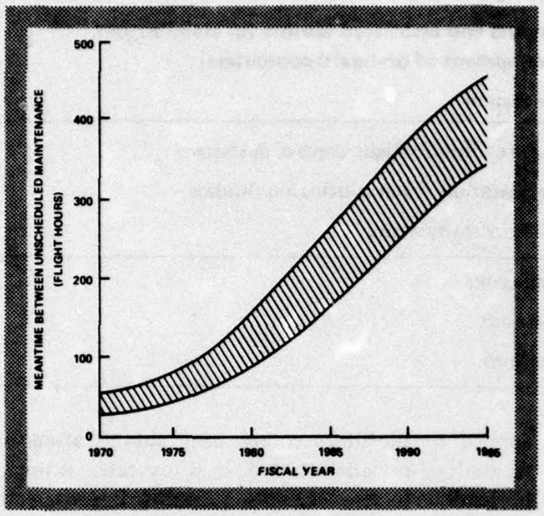


Figure AS–5. Flight control systems improvement goals.

ELECTRONIC CONTROL SYSTEM

Electronic flight control has thus far been the primary technique for implementing automatic flight control and stabilization. The technology in this area, particularly reliability, must be advanced to achieve fly-by-wire capability. A primary problem area in the development of reliable fly-by-wire control is proper redundancy management. Additionally, the concept of "power-by-wire" (whereby a complete hydraulic pump, reservoir, actuator, and control package is remotely located and powered by an electrical circuit) should be considered in association with fly-by-wire systems.

FLUIDIC CONTROL SYSTEM

The relatively new technology of fluidics offers a potential for a more reliable, less expensive flight control system. Single- and multi-axis stabilization and auto-pilot function have been demonstrated using hydrofluidics. Investigations must be conducted to advance the technology of sensing and transmission of signals to develop a system that will be a backup to the electronic system, or eventually, be adopted as the primary system.

The entire system should be evaluated in a dynamic simulation laboratory in which all test systems are assembled as they would be in the aircraft: hardware, wiring, hydraulics, computers, voting and switching logic, displays, controllers, and actuators. Simulated loads and airframe dynamic responses can be applied and system stability, performance, time constants, etc., can be observed and evaluated before commiting the system to flight.

FLIGHT CONTROL TOPICS SUMMARY

The research topics associated with the development of advanced systems for the three flight control system elements (listed in chronological order for electronic and fluidic systems) are shown in table AS–B. The development of the subelement items of the mechanical system have a direct relationship (impact) on the other system elements while each of the three elements have a profound impact on the development of advanced flight control system simulators.

Should each of the areas be adopted as an element of a unified research program, the objective goals indicated in chart AS–I could be achieved.

ENVIRONMENTAL CONTROL SYSTEMS

GENERAL

Army aircraft are required to fly in all weather conditions. Currently, this requirement for rotary-wing aircraft is limited to operating in reduced visibility at night and in clouds. To achieve true all-weather capability, these aircraft must be operable in icing conditions, dust clouds, and other natural and self-induced environments.

ICE PROTECTION SYSTEM

Ice protection systems are expected to be a requirement on virtually all future Army aircraft. Some areas, such as the windshield and engine-inlet, will require anti-icing. Other areas, such as rotor blades, can be adequately protected by a de-icing system. Ice detectors must be developed that will satisfy system requirements, and a method of describing icing conditions must be developed that is quantifiable and measurable rather than being merely

TABLE AS–B
FLIGHT CONTROL TOPICS SUMMARY

SUBDISCIPLINE	TOPIC
ELECTRONIC FLIGHT CONTROLS	• Develop stabilization systems suitable for electronic flight controls • Determine methods of load position and ground location sensing for precision hover (including effect of hoist cable dynamics) • Determine required inputs and associated sensors for stabilization system (including development of on-board computers) • Develop a fly-by-wire system
FLUIDIC FLIGHT CONTROL SYSTEM	• Determine applications for fluidic flight control systems • Develop stability augmentation systems utilizing fluidics • Develop backup flight control systems
IMPROVED MECHANICAL CONTROL SYSTEMS	• Develop improved bellcranks • Develop improved rod ends • Develop improved bearings

descriptive, such as "moderate" or "severe." The type of ice-protection system developed for specific aircraft can be tailored to the mission requirements of the aircraft.

The most critical area at present is the rotor blade de-icing. Current technology provides the capability to de-ice the rotor blades but the weight penalty is excessive. Work must be done to exploit new concepts of rotor blade de-icing which have acceptable penalties and to advance currently available concepts to eliminate the unacceptable penalties. Analytical, laboratory and flight investigations must be accomplished to thoroughly evaluate candidate concepts.

VIBRATION

The adverse vibratory environment in helicopters is a major contributor to the relatively short life of helicopter components and subsystems. The rotor-generated forces, which are carried through and, at times, amplified by the structure, impose vibratory forces on the structure and anything attached to it. The use of rotor-vibration isolators offers the potential of significant reduction, particularly in the low-frequency range. In some cases, active isolators will be required and, in others, passive or selftuning isolation will be sufficient. The mounting of subsystems and components on the structure affords another opportunity for isolation in a manner similar to that used in instrument mounts. These techniques can be applied to all future rotary wing aircraft after the technology is demonstrated. In many cases, it might be feasible to retrofit existing aircraft. Improvement in the vibratory environment imposed on aircraft subsystems depends upon advances in areas of aerodynamics and vehicle dynamics concerned with prediction, suppression, and isolation of vibrational loads.

Laboratory and flight tests of a passive vibration isolator have been accomplished with extremely good results. Vibration levels were reduced by factors of 2 to 4 with a weight penalty of approximately 2 percent of gross weight.

STATIC ELECTRICITY

The discharge of static electricity through the external cargo handling system has been a problem on all helicopters carrying externally suspended loads. The magnitude of the problem is a function of the gross weight of the helicopter. Thus, it can be expected to be of serious proportions on large cargo helicopters. A continuous discharge of the current during pickup and delivery of cargo would be desirable. Active corona discharges have not yet been satisfactory. Grounding wires are currently used, but these will not be acceptable in some operations. Additional work must be performed to develop a system that will adequately protect ground personnel and sensitive cargo during cargo handling operations.

ENVIRONMENTAL CONTROL TOPICS SUMMARY

The research topics pertaining to this subdiscipline are:

- Define and establish criteria for ice protection.
- Develop techniques for ice protection.
- Evaluate rotor vibration isolation techniques.
- Develop techniques for vibration isolation.
- Develop techniques for detection and dissipation of static electricity.

Should each of the areas be adopted as an element of a unified research program, the objective goals for environmental control system development indicated in chart AS–I could be achieved.

[illegible]

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the aircraft subsystems discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term subsystem objectives are primarily those that increase aircraft performance through increased efficiency and/or decreased weight or cost. Improved safety and survivability characteristics as well as reliability and maintainability are also of prime importance. The major near-term aircraft subsystem objectives, as established from chart AS–I, are stated below:

- Develop electrical power systems with 20 percent weight reduction
- Develop high-pressure hydraulic system with 350 hr MTBF, 30 percent weight savings, and 40 percent space savings.
- Develop pneumatic systems to replace hydraulic and electromechanical systems where advantageous.
- Develop landing gear systems with 25 percent improvement in flotation without weight increase.
- Develop ice protection system to permit operation into known icing conditions.

PROGRAM PRIORITIES

General. Table AS–C presents, in a prioritized listing, the aircraft subsystems subdiscipline, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

TABLE AS–C

PRIORITIZED AIRCRAFT SUBSYSTEMS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Performance	I	• Environmental control system	I	• Vehicle performance	I
• Weight	II	• Secondary power system	II	• Safety and survivability	II
• Volume	III	• Flight control system	III	• Reliability	III
				• Human factors	IV
		• Landing gear system	IV	• Life cycle costs	V

Technology Subdisciplines. Since there is little interdependence among the various aircraft subsystems, a priority ranking is meaningless. However, for specific aircraft system mission/performance requirements, subdisciplines within a subsystem can be identified and rated. The following subdisciplines are applicable to the various aircraft subsystems and would provide a basic list for evaluation purposes:

- Performance
- Weight
- Volume

Performance can be further divided into areas such as reliability, maintainability, mission effectiveness, and vulnerability.

Vehicle Subsystems. Vehicle subsystems, as related to aircraft subsystem technology, are the systems discussed in this section of the Plan and as summarized below:

- Secondary power system – includes power generation system, power distribution system and system components.
- *Landing gear system* – includes aircraft components and ground mobility systems.
- *Flight control system* – includes control input system, actuation system and system components.
- *Environment control system* – includes ice protection system, heating and ventilation system, air conditioning system, and adverse environmental conditions.

System Effectiveness. In the area of system effectiveness, the primary purpose of aircraft subsystems is to increase vehicle performance. Cost, R&M, human factors, and safety aspects all require careful consideration.

Priorities. With reference to table AS–C, the aircraft subsystem subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I representing the highest priority.

MAJOR THRUSTS/RATIONALE

A top priority technological thrust under the environmental control system would be the development of an advanced technology aircraft ice protection system with improved vehicle performance/mission capabilities and increased vehicle safety. Operational usage and mission effectiveness of present Army inventory helicopters are severely limited during adverse weather conditions and an ice protection system has been identified as an urgent need by USAEUR. All-weather flight capability is a requirement for UTTAS, HLH, and AAH.

Another high priority thrust would be the development of an advanced hydraulic system incorporating 8000 psi operating pressure with a 30 percent weight savings, 40 percent space savings, and increased MTBF.

A third high priority thrust would be the development of a pressureized air starting system for the ASH, which offers approximately a 30 percent weight savings over electrical starting while improving system performance.

LABORATORY PROJECTS IN AIRCRAFT SUBSYSTEMS

INTRODUCTION

Aircraft subsystem technological development effort is presently directed toward exploratory development (6.2) to increase knowledge and demonstrate advanced aircraft technology in the various subsystem disciplines. Funding limitations have significantly reduced efforts in this area. An advanced development (6.3) effort was initiated in FY77 to develop and evaluate lightweight and cost effective ice protection subsystems for application to existing and future generation Army helicopters.

All development efforts are conducted by AMARDL's Eustis Directorate at Fort Eustis, Virginia, either by in-house efforts or by contract.

DESCRIPTION OF PROJECT

Aircraft Subsystem Technology. Project 1F262209AH76-TA VIII is an exploratory development effort to advance the state-of-the-art for Army aircraft subsystems such that significant improvements in operational effectiveness and/or reduction in life cycle costs can be achieved. Detail investigations of ice protection, hydraulic, electrical, flight control, and other subsystems will be accomplished to define technology deficiencies and to establish means for the

elimination of those deficiencies. Initial areas of work will be directed toward: high-pressure system (up to 8000 psi) which offer significant weight reduction potential; battery charger-analyzer-aircraft interface; advanced long-life rod end bearings for flight controls; electromechanical flight control concept that offers greatly reduced system complexity and weight; verification of previously developed design criteria for elastomeric bearings; and advanced ice protection technology.

Helicopter Anti-Deicing. Project 1F263209D103 is an advanced development effort to develop and evaluate helicopter ice protection systems. Work performed under Project 1F26209AH76 and 1F263209DB38 has established realistic design criteria for helicopter ice protection systems, assessed the technology available for meeting ice protection requirements for present and future rotary wing aircraft, identified and developed solutions for technological voids found to exist in this area, the major area of lagging technology identified is the problem of rotor blade ice protection. Analysis of various concepts resulted in the selection of the cyclic-electrothermal rotor blade deicing concept as being one concept which can effectively meet existing or future ice protection requirements. Such a rotor blade deicing system has been proven feasible. Ice protection system penalties have been estimated for existing and future helicopters. Penalties attendant with rotor ice protection have been determined to be excessive for application to existing small helicopters such as the OH-6, OH-58, AH-1, and UH-1. Other concepts such as ice phobic coatings, micro-wave and vibration are being investigated under AH76. Test evaluations of new and promising blade deicing concepts will be initiated and will include the modification of a UH-1H to incorporate the deicing concept for engineering flight test purposes. Flight test evaluations will be initiated utilizing the existing icing R&D UH-1H helicopter to evaluate icing flight characteristics of ice detectors, Flight test instrumentation, armament subsystems, lightweight electrothermal rotor blade deicing systems.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the aircraft subsystems R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 and 6.3 aircraft subsystems efforts are shown in table AS–D. Included in the table is the ratio of aircraft subsystem efforts to the total 6.2 and 6.3 AMRDL R&D efforts.

TABLE AS–D

AIRCRAFT SUBSYSTEMS TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.2*	1F262209AH76-TA VIII	485	3%
6.3**	1F263209D103	425	3%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

**Based on Command Schedule dated 16 April 1976

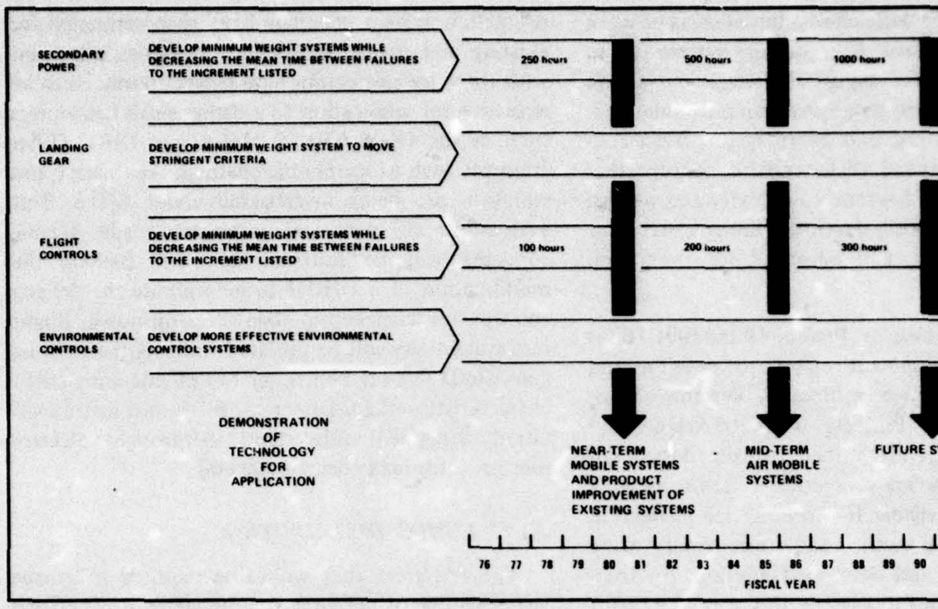


Chart AS–I. Objectives summary.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

GUNS

MISSILES AND ROCKETS

MUNITIONS

FIRE CONTROL

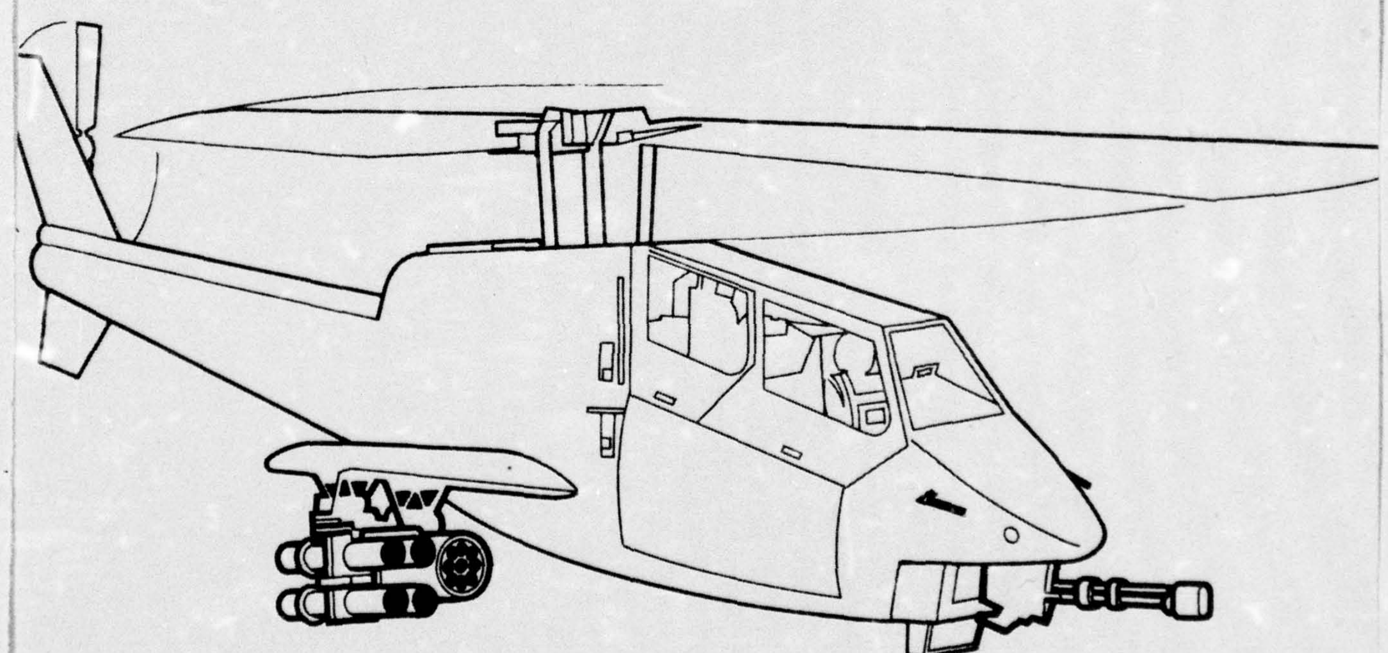
SYSTEM INTEGRATION

DISCUSSION SUMMARY

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

PROJECTS IN AIRCRAFT WEAPONIZATION



INTRODUCTION

The purpose of the Army aerial armament program is to provide the capability of delivering ordnance to destroy, neutralize, or suppress those targets jeopardizing ground or airborne forces in the conduct of the land combat role. For the purpose of this discussion, aerial armament system is defined as the complete weapon system, including not only the armament subsystem and the fire-control subsystem, but also the air vehicle. Aerial armament is primarily concerned with the effectiveness in ordnance delivery at a minimal cost. This capability depends on the adequacy and timeliness of the aerial armament technology base. Fundamental to the aerial armament technology are the following major areas: precision gun pointing; target detection, recognition, and tracking; warheads and terminal effects; and armament subsystem/air vehicle interface.

The U.S. Army Armament Command and the U.S. Army Missile Command have the responsibilities of developing weapon subsystems. More details of aircraft weaponization are found in their respective plans. However, Army Aviation Systems Command becomes a participant when aircraft application is first considered, even though aircraft types are undesignated, AVSCOM is responsible for providing the aircraft and properly integrating the weapons to assure effective total aerial weapon systems that directly address the Army needs. Figure AW–1 depicts the subsystems directly addressing the aircraft weaponization mission.

Although the weapon subsystems cited in figure AW–1 are designed mainly for fire support type aircraft systems, such as the AH–1 Cobra series, the AAH, and the second-generation attack helicopter, some may be candidates for other emerging or future aircraft systems by providing fire support capabilities. To develop an armament subsystem compatible with the designed aircraft, it is important to recognize all of its major components. The following technological discussion highlights the five areas of weapon subsystems major research and development efforts. The last item, which is the integration of the first four, is intended to exhibit total weapon subsystem considerations.

TECHNOLOGICAL DISCUSSION

GUNS

GENERAL

For gun-type subsystems, five important measures of performance are:

- Dispersion
- Rate of fire
- Time of flight
- Range
- Mean rounds between failure

The gun effectiveness is effected principally by:

- Angle of fall
- Dispersion
- Weapon-pointing accuracy

A near-term objective is performance data acquisition for the XM188 Gatling-Type Multi-Barrel Gun

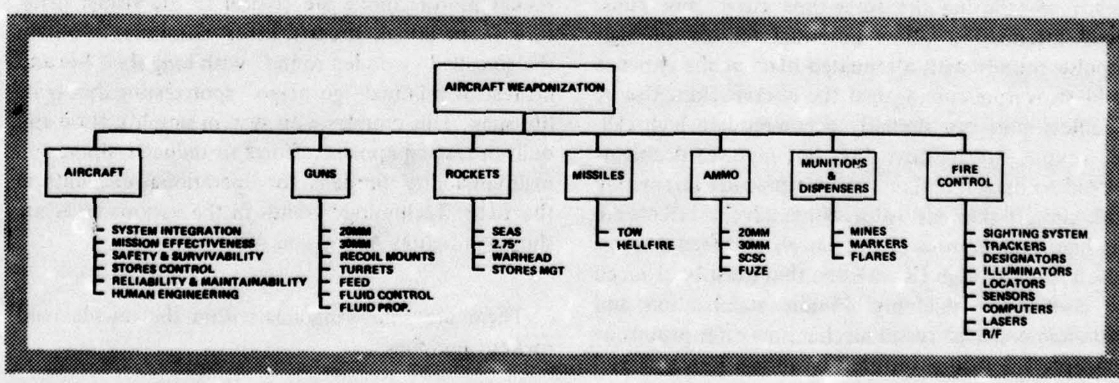


Figure AW–1. Aircraft weaponization subsystems.

and the XM230 Chain Gun. Objectives for the 1985-1990 timeframe are depicted by the following subsystems:

- Advanced Automatic Cannon Development Program
- Taper Bore Gun
- Liquid Propellant Guns

XM188/XM230

XM188 and XM230 data acquisition testing will provide gun/helicopter interaction data, weapons performance, reliability and maintainability data. This information will be applicable to the Advanced Attack Helicopter development and other proposed helicopter applications for these weapons.

ADVANCED AUTOMATIC CANNON

It is anticipated that the Advanced Automatic Cannon will have a multirole application. This project has been conceived to permit consideration of new concepts in medium caliber weapon development. Telescoped ammunition alternatives will be considered along with liquid propellant and taper bore weapons. The most promising design will be afforded the opportunity for future development.

GUN/AIRCRAFT INTERACTION

Various new concepts can make guns having high impulse munitions suitable for helicopter use by means of tailoring the force-time curve. For guns, recoil attenuation offers potential for use of high impulse rounds with attenuated blast at the expense of blast overpressure against the aircraft skin. Use of recoilless guns can similarly accommodate high caliber rounds in repetitive fire, but involves problems related to breech and muzzle overpressure interacting with aircraft skin and rotor. Other adverse effects are the high temperature of the barrels and feed systems which result in high IR emission that must be reduced by cooling or shielding. Fluidic stabilization and hydraulic constant recoil mechanisms offer promising concepts for future turreted weapons. Research and development efforts are needed in these areas and also in off-axis firings.

MISSILES AND ROCKETS

GENERAL

General technology advancement programs in missile and rocket research, as summarized in the Army Missile Plan, include such areas as:

- Propulsion
- Aerodynamics
- Missile guidance
- Missile control
- Subdiscipline design

There are, however, certain areas of endeavor that may take on overriding priority characteristics in aircraft weapon applications:

- Size and weight reduction of components and subsystems.
- Vulnerability reduction of the aircraft through visible signature reduction.
- Increasing shelf life of expendables.
- Increasing operational life of reusables.
- Expanding the environmental spectrum of operability.

Space and weight, being premium items that impact both sortie firepower and endurance, enhance the value of lightweight composite structural material and electronic integration circuit efforts. Minimizing beamwidths and suppression of sidelobes of active radiators, continued test and evaluation of passive seeker and tracking techniques, and reduction of rocket motor smoke are critical to the visible signature of the attack aircraft. Effort continues to obtain the so-called "wooden round" with long shelf life and no test or minimal "go no-go" spot testing during its life span. This couples with system simplification and built-in test equipment efforts to reduce training and maintainability burdens for operational elements in the field. Technology trends in the various areas are shown in figures AW–2 and AW–3.

There are four programs within the missiles and rockets discipline:

- Helicopter Launched Fire and Forget Antitank Missile System (HELLFIRE)

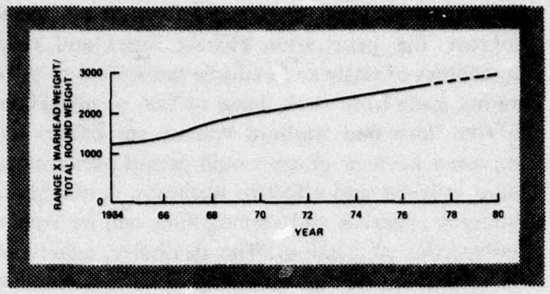


Figure AW–2. Free rocket design efficiency (combination of improved specific impulse and higher efficiency structures).

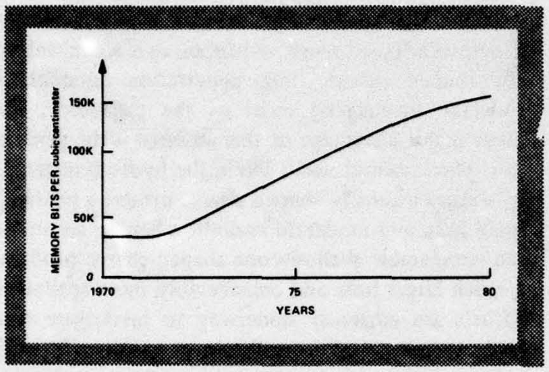


Figure AW–3. Semiconductor data handling capacity as a function of volume.

- Airborne Target Acquisition and Fire Control System (ATAFCS)
- Aircraft Rocket Subsystem (ARS)
- 2.75-inch Folding Fin Aerial Rocket Subsystem (FFAR)

The first two subsystems are operationally and functionally interrelated. While ARS and FFAR have interface couplings with HELLFIRE or TOW on some aircraft, they also have some installations and many subsystem and aircraft interaction characteristics that are totally independent of HELLFIRE, TOW, or any other guided missile subsystem.

The system descriptions of the programs listed above contain CONFIDENTIAL information and are presented in the Classified Annex to the Plan. (The Classified Annex is a supplement to the basic Plan.)

MUNITIONS

GENERAL

Aircraft weaponization requirements necessitate a variety of mechanisms capable of defeating a spectrum of targets, such as personnel, materiel, bunkers, and light and heavy armor in both the direct and indirect fire modes and a variety of countermeasure items. Related pacing technologies are germane to the nature of the proposed delivery means, whether they be gun launched, conveyed by missile or rocket, or released by dispenser. The delivery means consists of the following areas:

- Pyrotechnics
- Ammunition for aircraft weapons
- Munition handling

PYROTECHNICS

The goal of the pyrotechnics program is to provide the user an improved capability to recognize targets at night with near-daylight efficiency. Recent studies on pyrotechnic devices have shown them to be very ineffectively designed for military operations, primarily because of inadequate available information on illumination requirements. It is believed that by an overall systems approach, simple state-of-the-art changes can be incorporated in all existing flare systems that would significantly enhance their effectiveness by as much as an order of magnitude. Design of a Pyrotechnic Illuminating Flare System essentially consists of a compromise of the flare intensity, burning time, and parachute size. Pertinent to this compromise is definitive information on the illumination operational requirements and the effect of specific pyrotechnics parameters such as flicker, oscillation, and wind drift. In all these areas, data gaps exist. All present flare illuminating systems are designed to produce constant intensity for their total burning time (figures AW–4 and AW–5). Since all illuminating flare systems are suspended by parachute, the initial illumination on the ground is at its weakest; it gradually increases as the parachute descends. The initial illumination is inadequate, resulting in a warning to the enemy, allowing him to take cover before the illumination is adequate. These shortcomings can be eliminated by the incorporation of a varying intensity flare or increment flare.

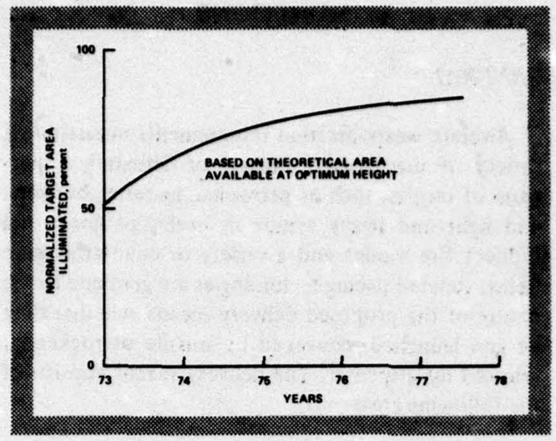


Figure AW–4. Target area illumination improvements.

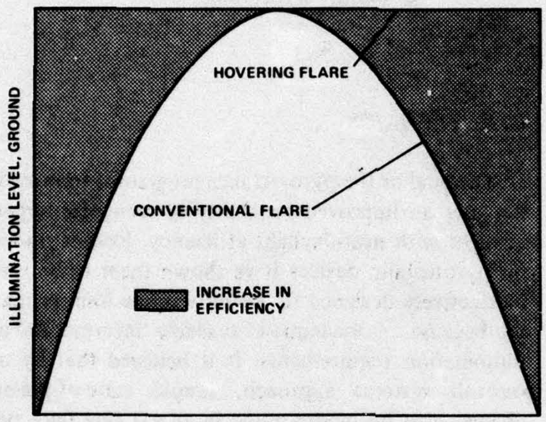


Figure AW–5. Illumination level improvements.

Improved illuminating flares will enhance the night operational capability of dependent weapon systems so as to permit surveillance and effective engagement of all targets within their mission areas during hours of darkness. The improved systems will also provide substantial reductions in logistics weight and volume, primarily because of increased effectiveness achieved by individual items through the pursuit and exploitation of opportunities and versatility offered by recent advances in pyrotechnic technology.

AMMUNITION FOR AIRCRAFT WEAPONS

General. An optimum ammunition mix study is required to permit greater effectiveness among flechette, HEDP, and WP smoke warheads against personnel and material targets. Research is needed to improve the penetration characteristics and range capabilities of single and multiple flechette-type penetrators made from steel, dense metals, or metal composites. Increased warhead volume per caliber and improved payload design would permit packaging of more efficient and effective warheads. A number of different materials and formulations will be studied for specific applications. The flexibility, adherence, flame protection, and durability of various ammunition coatings will be established. Propellant container formulations of artificial fibers combined with crystalline oxidizers will be investigated.

Shaped Charged Warheads. Shallow-cone shaped-charge warheads offer several advantages over conventionally shaped charges for defeat of light armor. Penetration is not sensitive to spin, as is a conventionally shaped charge; thus, penetration capability is constant throughout most of the trajectory. The other major advantage of this warhead is the penetration phenomenon itself. While the hydrodynamic jet of a conventionally shaped charge creates a relatively small hole and moderate spallation behind an armor, the comparable shallow-cone shaped-charge produces a much larger hole and considerably more spallation. Efforts are currently underway to investigate cone angle geometry, effects of spin and standoff, fuzing requirements, and characterization of the penetration phenomena.

20-mm Weapons. The discussion on this system contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

30-mm Weapons. The discussion on this system contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

40-mm Weapons. The discussion on this system contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

Fuzes. Several new fuzes are being investigated in the 6.1, 6.2, 6.3, and 6.4 technical programs. These unique designs simplify and enhance the performance of the shallow cone penetration in that clutter is removed from the nose of the projectile. It is expected that the miniaturized piezo initial base detonating fuze, the TRIBO luminescent base detonating fuze, and the plastic piezo detonating fuze will emerge from the technical program. Optimization studies will be performed in the automatic cannon

projectile calibers, and configurations of current interest, with particular attention to fuze warhead interface problems and antiarmor and antipersonnel lethality, will be developed. Improved graze sensitive fuze are being developed and fuze commonality is being investigated by examining possible applications of the 25 mm XM 714 Fuze to 30 mm projectiles. In addition to the above, base drag reduction devices, such as the fumer, will be developed to shorten the time of flight for air-to-ground projectiles.

Recoil Characteristics. Several concepts are currently being actively pursued to reduce peak recoil forces generated during the interior ballistic cycle and are described in programs such as Automatic Cannon Technology (ACT). These are the compressed propellant charge concept (figure AW–6) and rocket assisted projectiles. Another concept is a modified recoilless system in which the nozzle constitutes a segment of the cartridge case. Discarding sabot projectiles are being evaluated to increase range and terminal effectiveness, and provide the aircraft with a greater standoff capability. This results in increased aircraft survivability. However, incorporation of this concept into the complete weapon subsystem package necessitates examination of aircraft damage with respect to sabot fragments. The weapon system community is continually examining fuzing concepts that permit the application of specific munitions to a wider range of application. For fuzed munition, novel fuze concepts now under consideration would allow these items to be used in various roles such as airburst or point detonating. Adoption of these concepts would, in some instances, reduce the number of munition types required to complete a specified mission.

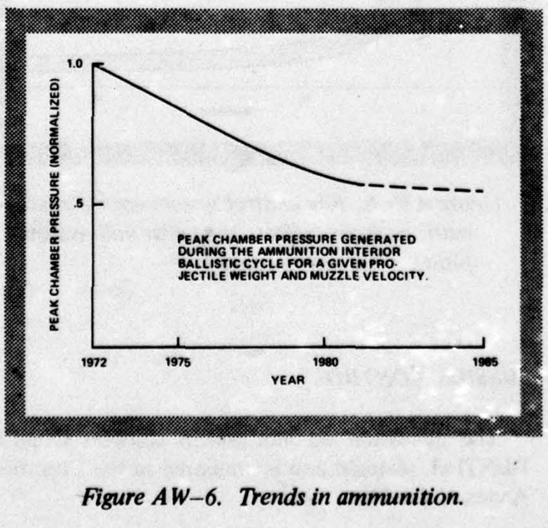


Figure AW–6. Trends in ammunition.

MUNITIONS HANDLING

Munitions handling is by no means peculiar to aircraft weapons systems, and the technology will bring about improvements in artillery, tank, and other weapons systems such as new feed techniques. Linkless, continuous, and disintegrating belts, caseless and combustible cartridge cases, and mechanisms for high-rate automatic selection and feeding must be developed for optimum compatibility with an aerial platform. The weight of the subsystems, be it rocket(s) launcher, air launched artillery or munition loaded dispensers, requires ground handling equipment not now available. The details of this effort are provided in the ground support section. The subsystem designer, however, must consider ease of attachment to the aircraft, since only a limited number of weapon subsystems can be carried by the aircraft per mission. The time required for attachment and checkout of a system must be minimized to permit rapid aircraft turnaround. Munitions rearming must normally be done by one or two men by hand while the subsystem is attached to the aircraft. Materials handling technology thus needs to be brought to bear to achieve desired improvements.

FIRE CONTROL

GENERAL

The generic area of control includes fire control, directional control and stabilization, and stores control. Fire control for aircraft weaponization is concerned with five major functions: target acquisition, target data evaluation, preparation of the fire mission, weapon aiming, and projectile delivery. Directional control and stabilization involve onboard equipment designed to adjust the elevation and traverse of weapons and maintain the aiming of the weapon to attain predetermined accuracy. Stores control consists of station, stores, and selectivity of munitions. The latter two control topics are discussed in the next subsection titled System Integration.

TARGET ACQUISITION

In fire control, long range detection and acquisition of hostile forces is critical to the successful use of aircraft weaponry. At present, optical and limited night/all-weather devices are restricted to a maximum practical range of 4 km. Some limiting factors are magnification, resolution, image or sensor spatial stabilization, and environmental effects. Similarly,

increased identification and recognition range capabilities are important to enhance engagement characteristics in reducing aircraft response time to a potentially hostile threat. An angular track of more accuracy can be approached with manual or full automatic techniques, provided the vibration response of the airframe is dampened by a rigid mounting structure or injected form of stabilization. Accurate range data for target tracking can similarly, although to a lesser degree, be influenced by air-frame flexure. The fire control prediction capability will have to compensate properly for aircraft flight conditions from the avionics package aspects, as well as the engagement parameters. Further, the influences of fire or launch of weapons on aircraft attitude can be provided by the fire control computer to the avionics in response to anticipatory control of the aircraft. Another interface of critical importance is that between the aircraft orientation and position relative to the target position and control of command guided munitions. Also of concern is the interface between the remote fuze setting system and the aircraft.

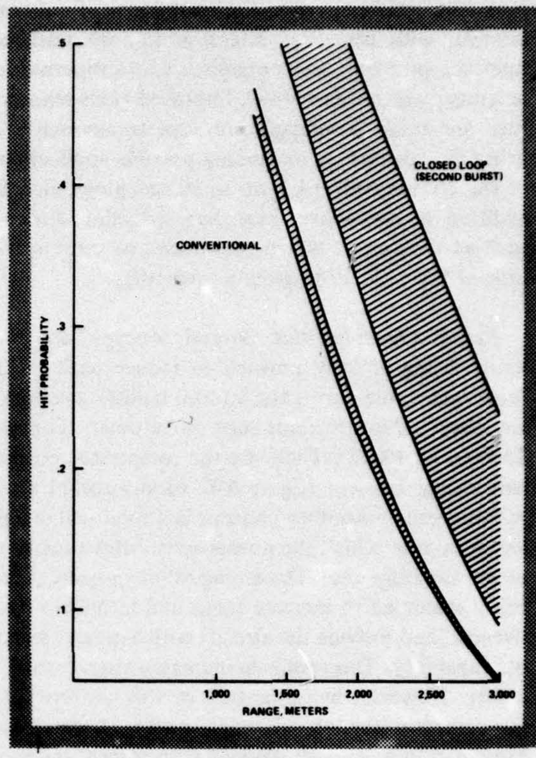


Figure AW–7. Burst hit probability: closed-loop versus conventional fire control system.

TARGET DATA EVALUATION

Gun errors can generally be classified into random errors and biased errors. Although the technology in space stabilization and feedback control for missiles and space programs is well established, the application to aircraft automatic cannons has been limited to the stabilization of the gunner's sight. Closed Loop Automatic Weapon Director is an evolutionary development in fire control techniques in systems designed for attack on point targets. The closed loop system will initially be integrated into an existing turret and gun system to establish both feasibility and potential. The basic operation is to fire a burst at the target, sense the error between the target line of sight and the burst impact with respect to the target, and generate correction signals that compensate for the error. This system will correct for errors from such things as downrange cross winds that are difficult or impossible to correct by other methods. Typically, hit probabilities can improve significantly in subsequent bursts (see figure AW–7), and the technology can effect a major reduction in system error from 10-15 mils to less than 5 mils (see figure AW–8). Also important is a possibility for improving system accuracy while reducing system cost. The subsystem applications include AH–1G and AAH with current and future high performance 20- to 30-mm guns.

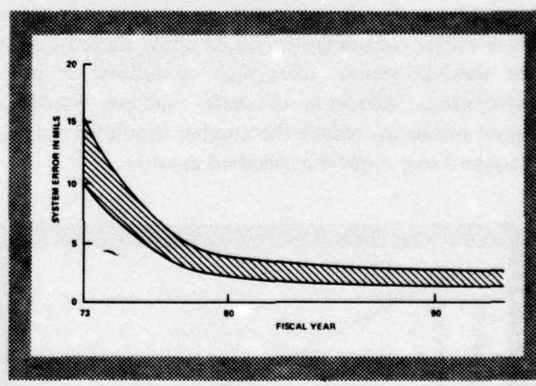


Figure AW–8. Fire control system error for automatic cannons (effects in angular milliradians (mils), 3000 meters range).

MISSILE CONTROL

The discussion on this system contains CONFIDENTIAL material and is presented in the Classified Annex to the Plan.

TARGET DETECTION

The day/night/all-weather capability of Army helicopter weapon systems is extremely complex and cannot be discussed here in great detail. The major approaches considered here are human vision, visual optical systems, image intensifiers (I^2), infrared, and radar. The curves shown in figure AW–9 are based on experimental equipment developed in the late 1960s, and the projections are based on 1971 estimates of improvements that could be made in the near timeframe. The human eye has severely limited capabilities at night or in adverse weather. These capabilities can be extended by use of magnified optical systems; however, the probability of detecting a target may decrease because of the limited field of view.

The IR and I^2 systems also have great potential. However, the operating environment has a major impact on system performance, and these impacts are not identical. For example, the I^2 devices are greatly affected by changing light levels, while the IR systems are nearly insensitive to light levels. Many other factors are also involved. Radar systems are primarily dependent on line-of-sight and the selected system parameters. Therefore, radar cannot be directly compared to any of the other systems. Because of the complexity of the technologies involved, their early stage of development, and hence their rapid growth in terms of capability and the impracticality of making direct comparisons, the curves shown in figure AW–9 should be used with extreme caution. The curves are intended to show only some of the technologies that may be applied to the day/night/all-weather operational problem. They also illustrate the fact that growth is occurring and a significant capability can be provided if required. Most likely, this would require the use of multisensors and would depend on the performance required, as well as size, weight, and cost considerations.

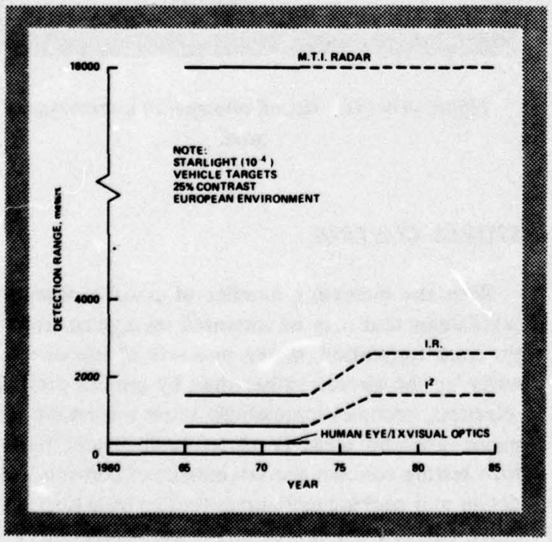


Figure AW–9. Trends in detection range.

SYSTEM INTEGRATION

GENERAL

Weaponization of Army aircraft is known to be a problem area in which the weapon and its vehicle are highly interactive in nature. In the past, attempts at weaponization of existing aircraft by "hanging on" a weapon have invariably produced results far short of expectations. Future developments will have to take into account the integration of the total weapon system very early in the developmental cycle. The areas in system integration include preliminary analyses, reliability, maintainability and safety considerations, aircraft structural mountings, and stores control. These areas are addressed in the following paragraphs. In addition to the basic technology impacts, there are interactions among them and with the aircraft that have considerable influence on mission effectiveness, survivability, mission endurance, and operational simplicity. Sortie effectiveness alone converts directly to reduce sortie requirements and exposure time. When improved effectiveness is coupled with the extension of standoff range, the rate of survivability improvement grows rapidly. Mission endurance is directly related to the required mission subsystems weight; therefore, integration programs should optimize endurance to achieve expected fire mission durations.

PRELIMINARY ANALYSIS

Initial system integration effort includes preliminary concepts, effectiveness, and performance analyses. Preliminary concept analysis formulates and investigates new and unique concepts that relate to problems affecting system performance. Effectiveness and performance analysis determine the impact of changes in weapon subsystem design parameters on performance of the system in its combat environment. Effectiveness analysis addresses weapon system characteristics in the context of its battlefield application. Performance analysis considers the weapon

system in greater engineering detail and addresses the effects of changes in design parameters on single unit combat activities. To address some problems, computer models are required to augment analysts' capabilities to address problems related to the interactive nature of the aircraft problem. Incorporation of cost into the analysis is necessary to approach solutions amenable to the needs of the Army. Tradeoffs are required between the operating parameters such as safe distance, reliability, and the effect on mission factors.

RELIABILITY AND MAINTAINABILITY

There is a recognized need to develop the capability to incorporate reliability and maintainability considerations early in the development cycle for systems and subsystems. An initial effort is underway which will lead to an identification of the critical subsystems and associated data gaps in which further reliability consideration are required. The testing of an integrated weapon system is a critical stage in weapon subsystem development. The fabrication and test of prototypes can be used to investigate delivery error budgets, reliability factors, human factors, etc., as they relate to system performance. The increased velocity of future aircraft will introduce new aerodynamic environments that affect subsystem design. The constraints to which weight, center of gravity, moments of inertia, aerodynamic drag, etc., and the tolerances to which these must be controlled will require a significant increase in the testing of a subsystem prior to its being incorporated into the complete system.

SYSTEM SAFETY

The use of weapon subsystems on an aircraft present safety problems to both the aircraft and the weapon subsystem. The weapon subsystem must be capable of withstanding the vibration environment peculiar to helicopters. The subsystem must be capable of being safely jettisoned while loaded or unloaded. Finally, the subsystem must be unarmed until it has achieved a safe separation distance from the aircraft. Aircraft racks, pylons, and controls provide the means for releasing the stores from the aircraft. Safety interlock devices must be used in the integration of weapon subsystems to the aircraft to prevent aircraft damage and mutual interaction of munitions, particularly in close proximity to the aircraft.

STRUCTURAL CONSIDERATIONS

Flexure of the aircraft structure at the location of the weapon is a problem that could seriously degrade the performance of weapon systems. Among the critical parameters are peak flexure and periodicity of structural response in relation to natural frequency of weapon structure. This area, particularly as applied to flexibly mounted weapons, has a direct effect on weapon directional control and stabilization. There also is a relationship between the airframe flexure at the location of weapon mounting and the round-to-round effects on an ordnance delivery and error budget. There is a need for improved mounting in aircraft structure and for damping of undesirable vibration-type effects. Further weapon stabilization can reduce undesirable transient disturbances to the aircraft structure resulting from launch or fire events. Further, performance can be enhanced by proper attention to initial design of the aircraft structure in providing improved mounting structures as well as optimal mounting locations (figure AW–10).

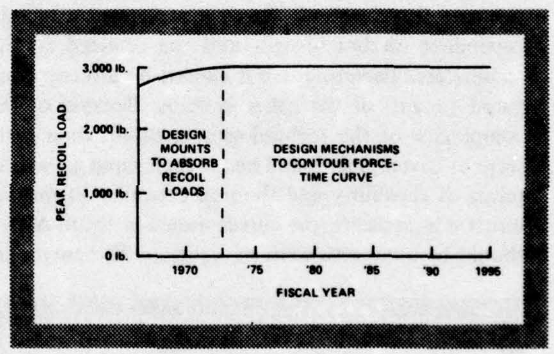


Figure AW–10. Recoil absorption improvement goal.

STORES CONTROL

With the increasing number of possible munition subsystems that may be mounted on a given aircraft, the need for station, stores, and rate of release selectivity by the aircrew rather than by ground preflight selection, becomes increasingly more important. The major problem areas in stores control and remote fuze setting concern the attainment of controls using design and packing techniques that provide high reliability and low maintenance, yet are compatible with the austere field conditions and severe vibration environments peculiar to Army aircraft. The major

interface considerations are physical location, compatibility with aircraft power, wiring, and other airborne electronics. Fire mission aircraft and particularly attack helicopters are normally designed for two-man crew operation of all on-board subsystems. It naturally follows that operational simplicity of any one subsystem reduces the overall workload. It equally follows that improved maintainability and ease of mission preparation in any subsystem will be reflected in mission availability and turnaround time.

DISCUSSION SUMMARY

The various aircraft weaponization topics discussed in this subsection can be summarized in chart AW–I, with the interrelationship between topics shown by the accompanying symmetric matrix.

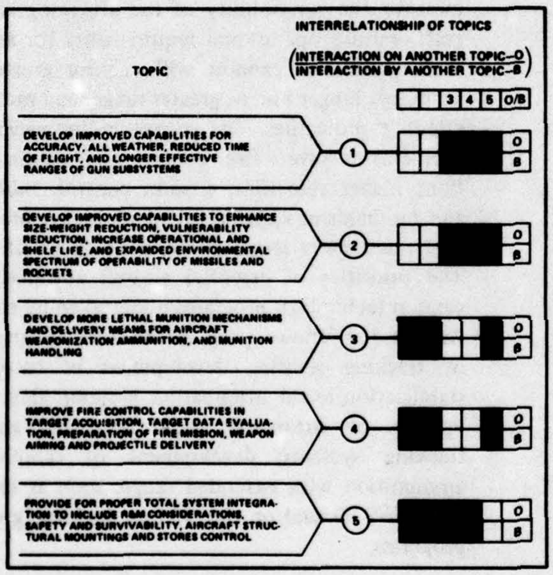


Chart AW-I. Aircraft weaponization topics summary.

[redacted]

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the aircraft weaponization discipline controlled by AMRDL. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives for the various subdisciplines with the aircraft weaponization technology can be established from the technical discussion presented in this section. The objectives are as follows:

- Increase accuracy, range, reliability, and lethality of automatic cannons.
- Increase flexibility, range, accuracy, and provide terminal homing in missiles and rockets.
- Increase range, airburst penetration, and provide common fuzing in munitions and dispensers.
- Improve target detection, tracking, range finding, and night/all weather capabilities in fire control.

PROGRAM PRIORITIES

General. Table AW–A presents, in a prioritized listing, the AMRDL aircraft weaponization subdisciplines, vehicle subdisciplines, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The AMRDL aircraft weaponization subdisciplines are represented by the major topical areas as discussed below:

- *Gun and mount* – pertains to efforts in precision gun pointing, recoil effects, and aircraft system performance to define advanced aircraft automatic cannon systems which offer capability for precision delivery of fire at long-range point and area targets.
- *Fire control* – pertains to efforts to develop the technology base and concepts for improving fire control capabilities for heliborn applications and includes improved target acquisition night/all weather devices and automatic target detection, recognition and tracking.

- *Aerial munition* – pertains to efforts in munition drag reduction via the fumer concept, in kinetic energy penetrator, and in shallow cone shaped charge.
- *Rocket accuracy* – pertains to the "total system" approach in achieving significant gains in accuracy and lethality through efforts in fire control, launcher design, motor design, fusing, and warheads.

Vehicle Subsystems. Vehicle subsystems, as related to aircraft weaponization technology, are categorized as follows:

- *Armament subsystems* – includes automatic cannon, rockets, missiles, aerial artillery and munitions.
- *Fire control subsystem* – includes detection, recognition, tracking, and designators.
- *Air vehicle subsystem* – includes avionics, structures, stability and control, aerodynamics, and propulsion.

System Effectiveness. In the area of system effectiveness, two principal areas are performance and life cycle costs. Performance is the effectiveness in the delivery of ordnance can be measured as probability of kill. This term is used as a general measure, and it implies not only kill but also probability of a hit, probability of a kill given a hit, degrees of kill, that is, incapacitation, immobility, as well as kill. Various performance capabilities are included. For example, they are lethality of the ordnance, ranges of armament subsystems, range of air vehicle, rate of ordnance delivery, air vehicle mobility and agility, and night/all weather capabilities in accurate delivery.

Priorities. With reference to table AW–A, the aircraft weaponization subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

MAJOR THRUST/RATIONALE

Assessment of the priority listing in table AW–A and the near-term objectives indicates the following major thrust areas:

- Develop precision gun-pointing and fire-and-forget technology for aerial armament subsystems to increase probability of kill. Current aircraft automatic cannon can operate only during the day, and under clear weather conditions. Standoff range must be increased and time to defeat the target must be decreased to improve the survivability of the attacking aircraft. Future operational requirements for aircraft automatic cannon will require greater accuracy, longer bursts, greater range, and more effective projectiles. The corresponding pacing problems involve: fire control and stabilization; higher velocities; erosion control; tubes and mechanisms suitable for much higher pressures; and more lethal projectiles (HE or KE). The priorities of essential aircraft automatic cannon technology programs undertaken by the Army are as follows: programs to increase range of tracking sensors; development of turret stabilization/recoil attenuation systems; development of automatic target detection and tracking systems; development of saboted ammunition with extended range, such as the AMCAWS 30 and/or the 30 mm lockless gun programs.

TABLE AW–A

PRIORITIZED AIRCRAFT WEAPONIZATION OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Gun and mount	I	• Armament subsystem	I	• Performance	I
• Fire control	II	• Fire control subsystem	II	• Life cycle costs	II
• Aerial munitions	III	• Air vehicle subsystem	III		
• Rocket accuracy	IV				

- Improve target detection, recognition, and tracking in the fire control subsystems to increase probability of kill. Current air-to-ground rocket technology is exemplified by the existing 2.75 inch Aircraft Rocket System. The major limitation is poor accuracy as a result of little or no fire control, and obsolete launcher designs. The pacing problem is achievement of delivery accuracy in a cross wind environment, with minimum adverse launcher reactions. High priority should be placed on establishing specific programs to generate a modern technology base for rockets. There is no base specifically related to rocket systems, as such. A "total system" approach including fire control, launcher design, motor design, fusing, and warheads, should be adopted to achieve significant accuracy and lethality gains.

- Develop warheads and terminal effects for aerial armament subsystems to increase probability of kill. Air-to-ground missile technology shows limitations in operational night and adverse weather environment with no capability to detect, track, lock-on and hit a target at night, through heavy fog, or during adverse weather. The principal problem is the achievement of night and adverse weather capabilities in guidance at an acceptable cost. High priorities have been assigned to terminal homing, guidance and control, all-weather and night operational systems development, and system modularity.

- Develop armament subsystem/air vehicle interface technology to enhance ordnance delivery and reduce life cycle cost. Aerial Field Artillery, Multi-Mode (AFAMM), is well recognized as a future aerial field artillery candidate which offers greater mobility, versatility, and responsiveness, as it satisfies the need for indirect/direct fire from the ground/air, detached/attached to an aircraft. This concept still requires demonstration in the technical feasibility, plus an in-depth assessment documenting the need/effectiveness of indirect fire from the air, threat and scenario that call for AFAMM, and cost leverage afforded by AFAMM.

PROJECTS IN AIRCRAFT WEAPONIZATION

INTRODUCTION

Aircraft weaponization technological development efforts are directed towards research and development to strengthen the technology base of aircraft weaponry. Aircraft weaponization engineering development efforts are aimed to provide the Army inventory with advanced aircraft weapons and improved munitions. The work is conducted primarily by the U.S. Army Armament Command, the U.S. Army Missile Command, the Army Ballistic Research Laboratories, the Project Manager of Aerial Rockets, and the Army Test and Evaluation Command. Additionally, aircraft-weapon subsystem interface capability and advanced development weapon system programs are conducted by the U.S. Army Aviation Systems Command through the Directorate for Research, Development and Engineering and the Air Mobility Research and Development Laboratory.

DESCRIPTION OF AVSCOM PROJECTS

Aircraft Weapons Technology. Project 1F262201DH96 is an exploratory development effort conducted by AMRDL to generate concepts and to develop technological advances necessary for performance, life, and operation for aircraft weaponization applications. Specifically, there are four areas of research and development: gun and mount, fire control, aerial munitions, and rocket accuracy. For gun and mount, the basic methodology and critical components that are needed to improve significantly the hit probability of helicopter automatic cannon systems are developed; the relative error contributions resulting from the dynamic environment of the gun platform, and techniques to reduce effect of environment or boresight, are determined. Efforts in this area address analytical models for improved design concepts, improved soft recoil methods, and common gun and ammunition technology for multiple weapon applications. For fire control, the emphasis is on analytical and simulation studies, improvement in long-range target detection/recognition capability by use of target cueing and image enhancement techniques, evaluation of the potential of various advanced fire-control hardware, and the generation of realistic system analysis models for improved night/all-weather fire-control systems. Efforts in this area address automatic target cueing concepts, error budget analysis for multi-weapon fire

control system test bed, and application of millimeter wave radar concepts. Aerial munition work is pursued to expand the technology baseline in the air-to-ground role by the systematic investigation of the critical parameters necessary for increased system effectiveness. The technology base includes work in the following major areas, for shallow-cone shaped-charge concept spin insensitivity, merits of spitback fuzing, scaling, fragmentation effects, and behind armor effects. For rocket accuracy, a "total system" approach (including fire control, launcher design, motor design, fuzing, and warheads) should be adopted to generate a modern technology base to effect product-improved rockets. Of immediate concern is the need to develop concepts to make the placement of submunitions into a target area relatively independent of variations in rocket trajectory and platform stability. One approach will be to investigate the incorporation of a drag device on each submunition to terminate its trajectory and induce a vertical descent near the point of ejection. Other concepts are in the areas of low cost methods for inducing discrete terminal trajectory corrections and developing a target marking capability to allow integrated use of cannon and rockets on selected targets.

Aircraft Gun-Type Weapons (6.3). Project 1F263206D044 is an advanced development effort conducted by AVSCOM RD&E to improve the capability of aircraft weapon systems employing gun-type weapons. This will be achieved by improving system accuracy, terminal effects, airframe compatibility, and overall system reliability. Specific areas of investigation will include weapon system stabilization techniques, recoil soft mounting, improvement in the reliability of weapons and system components, and increased warhead size, velocity, and range. One area of work is in components development, which provides the advanced development of new gun-type weapon components concepts, and subsequent integration for extended ranges, reduced time of flight, improved accuracy, and improved maintenance/reliability. An additional area is to work on the shallow-cone shaped-charge concept as a retrofit in the XM552 HEDP projectile and to establish the shallow cone as the primary armor defeat mechanism in advanced automatic systems. The approach is to use the XM552 HEDP cartridge as a vehicle for investigating shallow-cone applications and shallow cone concept with spitback tube. The plan is to establish feasibility in the 6.2 effort and develop applications in this, the 6.3 effort.

Aircraft Weapon Fire Control. Project 1F263206D043 is an advanced development effort conducted by AVSCOM RD&E to design, fabricate, and test advanced development hardware of fire-control devices for aircraft weaponization systems. Data derived from the development and test of this experimental hardware will contribute directly to the engineering development of operational test prototypes. Several factors make first-round hits increasingly more difficult – among them, increased aircraft performance, the availability of a wide variety of weapons (with corresponding variations in ballistics), and increased operation in adverse visibility environments (night/all-weather, vegetation/background clutter). The component and system efforts under this project provide for operation at night and in adverse weather. Types of equipment will include, but not limited to, computers, passive automatic trackers, active ranging and tracking, night/all-weather acquisition and targeting systems, radar fire control, infrared fire control, control equipment, heads-up displays, and other sighting and viewing devices. These efforts also support the development activities for the AH–1, AAH, and ASH aircraft. There are five major areas which are detailed below.

The first area is automatic tracking (passive), which calls for the development of flyable hardware for fully automatic, highly sensitive, accurate, target-tracking devices and subsystems, which will be integrated into fire-control sighting systems having direct or remote view. The device will, by virtue of radiant energy emanating from the target, remain automatically locked on the target, despite movement of the aircraft or target. Devices of this type are required so that precision tracking of targets can be accomplished without utilizing an operator, whose response times are not compatible with the performance required. Application lies in determining accurate target position and velocity information for gun, rocket, missile and free-fall weapon delivery computations, as well as in providing the means for accurately pointing targeting sensors such as laser designators, rangefinders, missile trackers, etc. Hardware development includes imaging and nonimaging sensors, and special-purpose signal processing electronics systems that may be interfaced with existing remote imaging sensors, such as TV and FLIR, which generate tracing error signals.

The second area is ranging and tracking (active). Accurate range data and tracking capability are two of the primary inputs required for successful fire

control; at the same time, these two factors also represent a significant portion of the fire control cost. This task develops a ranging and tracking system that represents optimum system performance for the dollars expended. Technological advances will be investigated to determine if a smaller, lighter weight system with improved reliability ranging and tracking can be developed. Primary hardware components under investigation are the neodymium laser rangefinder and stabilized gimbal/mirror systems. Turreted 20-mm and 30-mm weapons are planned additions to the helicopter airframe; the effects of gun blast, shock, and vibration will also be evaluated to determine the effects on the tracking system. The addition of semiactive and active autotracking devices to stabilized systems will also be evaluated. Further investigations of the mask mounted sight are planned to provide positive results as a potential means of reducing aircraft vulnerability while achieving target acquisition and tracking.

The third area is in the advanced development of selected night/adverse weather fire-control systems which can detect, acquire, recognize, track, and deliver weapons fire in a mid-intensity conflict. Candidate systems are imaging infrared, advanced low-light-level TV, and stationary and moving target radar. These systems will be considered as primary sighting systems, either singly, or in combination. Other components, such as laser rangefinders, computers, and tracking processors, will be developed under other DO43 tasks and then integrated into the complete system under this task.

The fourth area is to develop and evaluate heliborne, fire-control full-solution and integrate them into the aircraft (i.e., airframe, prime electrical power) navigation and avionics equipment. Results will provide data for future weapon systems performance and design specifications. The multi-weapon fire-control system (MWFCS) XM-127 will be utilized as one of the basic systems for integration of components. The feasibility of applying closed loop techniques to helicopter fire-control systems will be evaluated. Evaluation and identification of the design problems and performance parameters of fire-control components will reduce the normal development cycle and make possible an early determination of maintainability and support requirements.

The fifth area is in sighting and viewing devices. Present and future airborne weapon systems require man-in-the-loop sighting or viewing devices as a method of coupling the user to a target. Improvement of the user's capability has a direct impact on the survivability and effectiveness of his mission in a combat environment. This task provides sighting and viewing devices for present and future fire-control systems for effective Army helicopter weapon systems. The devices generated will be used by the pilot or copilot (or both) in a coordinated effort for target acquisition, tracking, and engagement. Emphasis will be directed towards computer-controlled display sights, head-up displays, helmet displays and sights, gimballed optical sights, fire-control sensors, and miniaturized display processor. An investigation will be started to formulate design concepts for canopy mounted sighting systems, the objective is to enhance survivability by degrading the enemy's ability to visually detect or locate the aircraft.

Aircraft Gun-Type Weapons (6.4). Project 1F264202D133 is an engineering development effort conducted by AVSCOM RD&E designed to provide the Army inventory with an advanced automatic aircraft weapon and improved ammunition in the 30-mm class. The primary intended application of the weapon is for Army helicopters; a second application is planned for ground vehicle weapon. Both uses should optimize firepower effectiveness. The objective is to design and develop a lightweight, low-cost cartridge compatible with an improved graze-sensitive fuze and a liner optimized for penetration at extended ranges. Cobra enhanced weapon fire control will be developed and analyzed for improved gun aiming performance. Fire control candidate components will be evaluated. This work will be applicable to the requirements of aircraft rocket system fire control.

The improved 30-mm program has as its purpose the design, development, and testing (up to the point of ET) of improved XM552 (30 mm) ammunition incorporating an aluminum casing, an improved graze-sensitive fuze, and a liner optimized for penetration at extended ranges. The program also calls for engineering support and services, hardware, and testing necessary to accomplish the foregoing. Two competitive efforts were funded to investigate the incorporation of graze sensitivity in the XM579 fuze. Fuzes from this effort were evaluated, and the best design was selected for development. Spin vs. range data were obtained. To achieve commonality of ammunition components, the XM714 fuze has been integrated into a feasibility program and evaluated for potential application. Another effort is directed toward designing a producible weapon with extended

range and superior terminal effects. The primary application is intended for Army aircraft to optimize air-to-ground firepower effectiveness. Trunnion impulse would be minimized by a constant force, recoil system design. Self-powered or external gun power will be considered. Other efforts include tests of the XM188 and XM230 30-mm guns to determine weapon-operating characteristics and performance parameters. The testing will be conducted on the six-degrees-of-freedom simulator in the Keith L. Ware Simulation Center at Rock Island Arsenal. Several aircraft system structural rigidities will be simulated during testing. The results are applied to the Army attack aircraft which are planned to incorporate these weapons.

Work is underway in the enhanced Cobra gun system to develop an antipersonnel and antimateriel weapon system for the attack helicopter capable of sustaining long-range target fire against light armor vehicles and suppressing ground fire with a high casualty rate. The system will provide the tactical usefulness and versatility of a flexible installation, greatly enhancing mission accomplishments and survivability of the aircraft and crew. The system will represent current state-of-the-art design. The turret will be a modified XM97 20-mm turret capable of accepting a 30-mm weapon. The system may be designed to use XM552 or ADEN/DEFA 30-mm ammunition. The ammunition storage and feed system will be a linked system capable of handling 500 rounds of ammunition at a rate of 600 shots per minute. Major subassemblies include a flexible turret assembly, linked ammunition storage and feed system, electronic control assemblies, and gunner/pilot control panels. The 30-mm round is selected over the M50 series 20-mm rounds because of its superior terminal effects. In conjunction with the above, a fire-control program has the purpose to develop a fire-control full-solution for the turret weapon system on the AH-1G helicopter. The subsystem will enhance the delivery accuracy of the turreted automatic weapon. The subsystem will consist of a stabilized sight with magnification, a laser rangefinder, a fire-control computer, and an air data sensor to measure temperature and pressure. The effort will utilize the information and data obtained from advanced development tasks in aircraft fire control where mid-intensity conflict performance is a primary consideration.

Aircraft Rocket System. Project 1F264202DL62 is an engineering development effort conducted by AVSCOM RD&E to develop an aircraft rocket subsystem that will provide a significant increase in standoff capability, accuracy, and target effects necessary to provide adequate direct aerial fire support to ground maneuver forces operating in all intensities of conflict. In addition to the development of a rocket airframe, this effort includes the development of lethal, multipurpose warheads for use against armored targets, material, and personnel. Another part of this project is to develop a full-solution fire-control subsystem to enhance the accuracy of free rockets from Army helicopters. The subsystem will consist of a pilot's heads-up display, an air data sensor, and a laser rangefinder system. The effort will utilize the information and data obtained from advanced development tasks in aircraft fire control. Performance in mid-intensity conflicts is a primary consideration. The technology developed could be applied to the enhanced Cobra.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objectives of the aircraft weaponization R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2, 6.3, and 6.4 aircraft weaponization R&D efforts are listed in table AW–B.

TABLE AW–B
AIRCRAFT WEAPONIZATION TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) OF COMMAND SCHEDULE FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
		AMRDL	RD&E
6.2	1F262201DH96	1650	•
6.3	1F263206D043		1290
6.3	1F263206D044		1350
6.4	1F264202D133		1300
6.4	1F264202DL62		1400

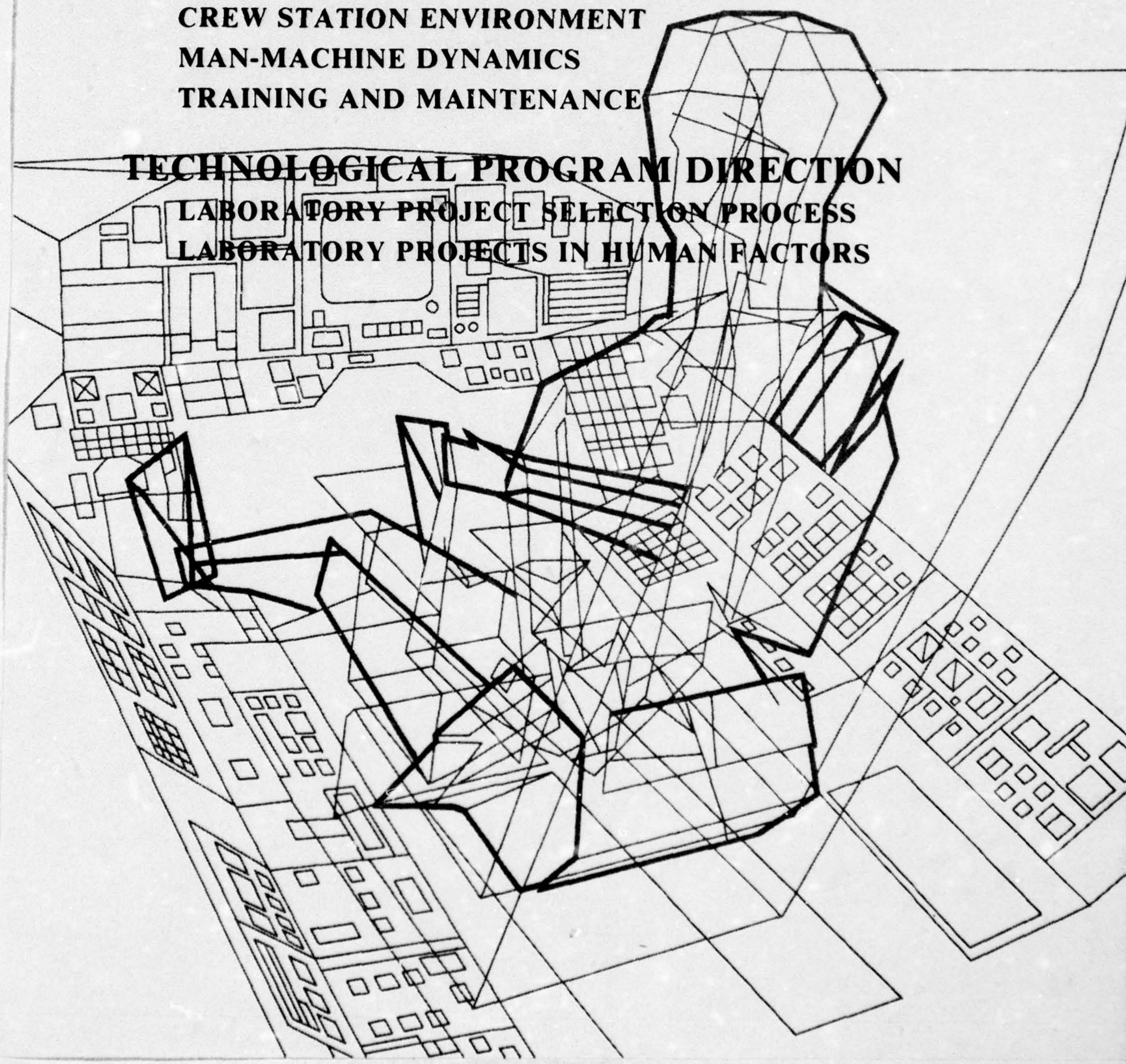
INTRODUCTION

TECHNOLOGICAL DISCUSSION

HUMAN PERFORMANCE TECHNOLOGY
CREW STATION ENVIRONMENT
MAN-MACHINE DYNAMICS
TRAINING AND MAINTENANCE

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS
LABORATORY PROJECTS IN HUMAN FACTORS



INTRODUCTION

In Army aviation, the human factors (HF) discipline can be described as a point of view, a technology, and a process. For current and foreseeable weapons systems, the basic limits on system performance are imposed by the men in the loop rather than by the capabilities of the system machinery. In general, technological advances have imposed increasing demands on system operators in the skill with which they employ their sensory, mental, and motor faculties. Currently, the personnel costs associated with having and using weapons systems exceed hardware costs, and this trend is growing steadily. Recognition of these basic realities and a determination to apply appropriate problem solving is the fundamental human factors *point of view*. The human factors *technology* consists of a scientific and technical body of knowledge already extant, as well as the procedures and facilities for its continued expansion. Although its formal history is short, its volume is very extensive and its diversity is exceeded only by that of the potential users' problems. The human factors *process* is one in which organizational policy and procedures are marshalled to ensure that results available from technology are fully utilized in the development and use of weapon system equipment.

Army aviation has set high goals for itself in its determination to adapt the next generation of aircraft to new mission requirements posed by night and all-weather operation, nap-of-the-earth flight tactics, and operational capability in mid-intensity threat environments. These requirements will call for a new level of sophistication in Army equipment. The challenging demands placed on flight and ground crews will certainly be unique and may prove to be more difficult than any other aviation assignments in the history of flight! Success in meeting these objectives will positively require departures from conventional helicopter design concepts. Human factors can play a vital role in achieving this success by capitalizing on the human factors technology now available; by skillful allocation of resources and effort to fill present technology voids with shrinking research funds; and by innovative application of management skills to streamline the human factors process and make it more effective.

Human factors efforts span all phases of the system development process from research and development to test and evaluation. Throughout, the objective is better system performance as a result of good man-machine integration. Effectiveness in this process requires relevant research, sound design and development methods, proven engineering criteria, and valid test or demonstration procedures. The subdisciplines discussed below are one way of partitioning the interrelated areas in which technology base development can provide coordinated progress in the RDT&E process. Human Performance Technology refers to methodology and descriptive investigations into the fundamental processes of human behavior in performing aircrew duties. Observation recording, measuring and assessing aircrew performance are discussed in terms of new, more effective research and engineering methods. The Crew Station Environment section covers development and engineering requirements associated with aspects of the cockpit man-machine interface which are static in nature. It includes anthropometry, control-display layout, visibility envelopes, environmental stressors (noise, heat, vibration, lighting) and the long-term effects of sustained crew duty workloads. Man-machine interactions which are dynamic in nature are discussed in the following section, Man-Machine Dynamics. It covers display, control, information requirements and other general issues in cockpit equipment employed by the aircrew. This area offers the greatest opportunity for hardware innovations, for cost control and for enhanced system performance. The section titled Training and Maintenance discusses the prospects for system design procedures with the stated objective of controlling training, proficiency, maintenance, and other system-related personnel costs.

The final section discusses two basic issues in Flight Simulation: determining the visual, motion, and other design requirements for an advanced flight simulator for system research and development, and the development of specific R&D plans and strategies for its use.

This Human Factors Plan identifies current problem areas and qualitative improvement goals for R&D achievement in several time periods. The objectives and the program elements of the plan are summarized in each subsection of the technological discussion and will permit additional specific goals to be defined. Priority in the development of specific projects in support of the program goals will be assigned to those efforts (1) for which the need is greatest (considering especially the timing of systems now in development); (2) for which human factors contributions are clearly achievable in useful form; and (3) for which the maximum resultant payoff in improved system

effectiveness can be obtained. Emphasis will also be placed upon those objectives most directly related to the AMC major thrusts in the areas of night vision and night operations.

TECHNOLOGICAL DISCUSSION

HUMAN PERFORMANCE TECHNOLOGY

For Army aviation, the gaps in HF technology that most significantly limit its usefulness are basic problems in measurement, assessment, and prediction of human performance, and in identifying the relationship between operator performance and overall system effectiveness. The central role of pilot and aircrew performance in achieving maximum system effectiveness is well recognized. Most accounts deal with system limitations due to pilot and aircrew performance in terms of an operator workload or task-load approach. Although many methods are currently employed for describing, assessing, and dealing experimentally with pilot and crew performance, all of them are lacking in either objectivity or generality, or both. These limitations have prevented the full development and use of task-loading and other systematic approaches in both general and quantitative forms. As a secondary effect, they have delayed efforts to relate crew performance variables to system effectiveness.

Improvements in this area are required to standardize the measurement of crew performance in operational settings, to provide full objectivity of measurement where possible, and to improve the uniformity of subjective measurement procedures where these remain necessary. The main goal is the identification of objective and quantitative measurement procedures that can be widely applied to different crew stations, tasks, and missions; and to equipment, mockups, and simulators in varying degrees of completeness. It will provide a common basis for correlation and evaluation of measurement data, and will permit better comparison and interpretation of experimental results.

Ultimately, basic improvements in the tools of human performance technology will permit the development of full and systematic theoretical accounts of man-machine interaction. Translated into useful results, this will permit the identification of machine design variables and properties that can contribute to efficient human performance and ultimately optimize system effectiveness. Tradeoffs between system cost and system performance can be specified directly through the mediating variables measurable as human performance parameters. The general and specific effects of stressors (such as fatigue, high task-loading, combat-induced emotional states) and environmental conditions (such as heat and noise) can also be accounted for in a useful and systematic way. It will be possible using these new methods to compare the relative payoff in system performance from any proposed change in the man-machine interface, such as the addition or deletion of specific equipment, changes in equipment layout, changes in training or operational procedures, and improvements in environmental control systems. The need for these capabilities is most acute in the cockpit-crewstation design areas, but the above remarks also apply to maintenance, servicing, and other areas in which men serve as system elements. The problems are general and can be seen in each of the more specific problem areas detailed in the sections that follow.

Although considerable success has been achieved in the development of mathematical representations of other components of aircraft systems, modeling of pilot and crew performance has not produced comprehensive and useful results. Successful mathematical models of pilot and crew behavior are needed in forms useful for stability and control or handling qualities analysis and simulations, for display and information processing analysis of display design and implementation requirements, and in forms that will identify marginal effects in order to account for individual variability of pilot and crew behavior and deviations from optimum designs. Improvements in this area can eliminate the present dependence on small nonrandom samples of actual human performance in the evaluation of new aircraft system concepts.

The objectives of the R&D program in expanding the capabilities of human performance technology are detailed in chart HF–I, along with elements of the program directed toward those objectives.

CREW STATION ENVIRONMENT

Man-machine interactions can be roughly divided into static and dynamic categories. This section deals with those aspects of aircraft crewstation design and environmental control involving relatively static man-machine relationships. These factors include for example, cockpit anthropometry, accessibility of controls and displays, egress provisions, seat support and

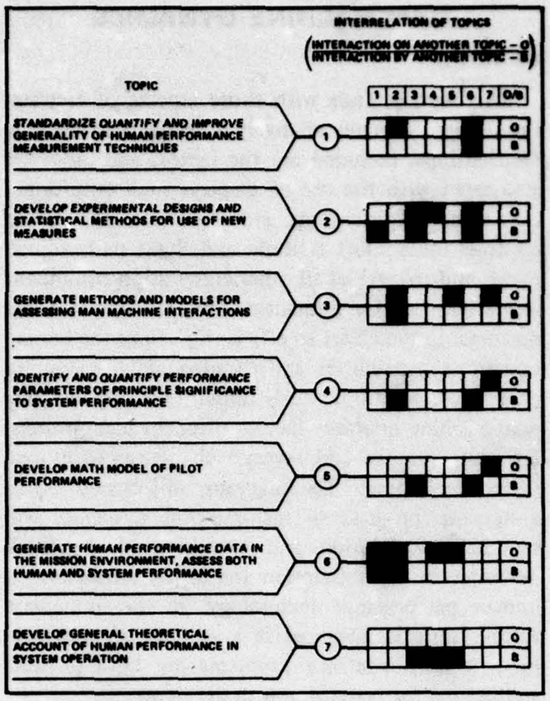


Chart HF–I. Human performance technology.

retention provisions, external visibility, and environmental factors such as lighting, noise, vibration, and other life support control provisions. Human factors technology has been most successful in developing design guidelines and principles in this area. Continued development is needed, however, to meet the requirements of new and more demanding mission capabilities and to allow the efficient utilization of new concepts and equipment in crewstation design.

Currently available design criteria are often stated only in qualitative terms or are in the form of a single value design goal. In most cases, the research supporting these findings has been oriented to seeking optimal values for a given factor, with other factors sampled only in a narrow range. Thus, the interactions between different static design factors, and also the marginal effects of deviation from an optimum value, are poorly defined. The adaptability and flexibility of the human operator (the properties which are most heavily relied upon in his role as system operator) also allow him to accommodate relatively large deviations from optimum design in most of the crewstation design factors. When this occurs, the operator is said to adapt to the nonoptimal condition or to compensate for it. This often diminishes his capability for dealing with other stressors and tasks, but the nature of these effects is poorly defined. Designers have the difficult task of balancing competing design guidelines and single-valued design goals in the overall task of creating crewstations for specific missions. They would be much better served if the relationships between competing design objectives were stated in terms of their mutual effect on operator performance and if they could determine the operator performance "cost" associated with compensating for inadequate environmental conditions. Such refinements in the criteria for temperature, noise, vibration control, visibility, and other static crewstation design requirements are now required to permit the creation of suitable crewstations for the expanded operating envelopes and mission requirements of the Army's future aircraft.

New developments in other technologies are changing old concepts of crewstation design. Refinements in static crewstation design criteria are needed to permit the fullest possible utilization of these developments in effective ways. New materials, sound suppression treatments, environmental control devices, lighting equipment, display and control equipment, improvements in seat comfort, retention and protection, and many other developments impact the various static crewstation factors. Criteria for crewstation static factors must be made to keep pace with these advancing technologies.

As the relationships between significant crewstation environment factors are defined, and as their mutual effects on crew performance are better established, specific programs addressing long-standing crewstation deficiencies can be undertaken. The long range objective is to obtain maximum system effectiveness by providing crewstation designs that permit optimal human performance. Crew comfort or convenience, *per se*, will no doubt be improved; but this is a side effect rather than the objective. Specific program goals in improving the crewstation environment include the following:

- Reduce the adverse effects on crew performance of noise, temperature, humidity, vibration, and other environmental stressors.
- Reduce the adverse effects on crew performance due to seat, restraint, armor and other crew furnishings, and personnel equipment.
- Resolve the controversial issues involving red vs. white cockpit lighting concepts and the relation

of this and other aspects of cockpit vision provisions (glare, reflections, etc.) to specific mission requirements.

- Provide for the higher angular accelerations associated with high-performance aircraft and NOE flight tactics.
- Establish requirements, provisions, and criteria for crew escape and ejection systems as technology becomes available. Provide suitable egress, ditching, and crash protection criteria for basic crewstation designs.

The overall objectives of human factors technology in the crewstation environment area include the development of matured systematic accounts relating design factors, operator performance, and mission requirements. Achievement of this objective will permit more effective determination of crew requirements and crewstation configurations for specific missions, and will permit more efficient allocation of functions between crewmen and between man and machine for identified mission objectives. The R&D program objectives and program elements related to crewstation environment factors are presented in chart HF–II.

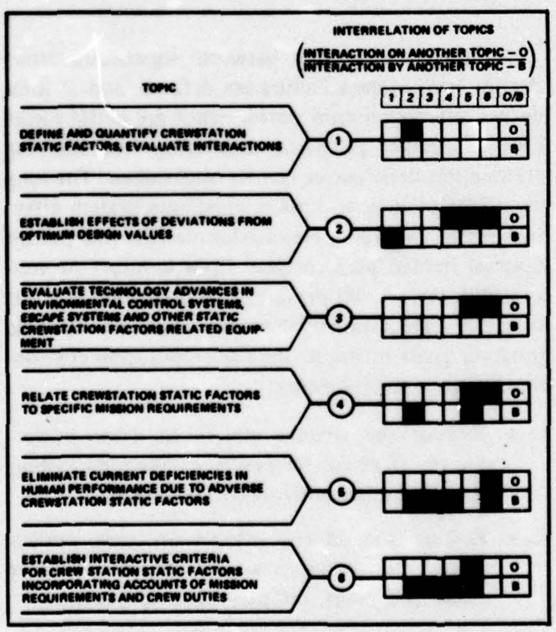


Chart HF–II. Crew station environment.

MAN-MACHINE DYNAMICS

GENERAL

This section deals with those aspects of crewstation design involving relatively dynamic man-machine relationships. Included are the factors and processes associated with the use of displays such as information transfer, processing, and evaluation; the use of controls for aircraft attitude and flight path adjustment; and the use of all other crewstation equipment requiring attentive interaction between operator and machine. In the effort to efficiently utilize the human operator's capabilities and to adequately accommodate the human operator's limitations, the dynamic man-machine interface factors offer the most promising opportunities and severest challenges to human factors technology. The long range objective of broad systematic progress in man-machine dynamics will require consolidation and extension of the work described in this subsection and in the subsection on human performance technology. In the immediate future, specific advances in a number of individual man-machine interface problems are both possible and needed for systems now in development.

The number of possibilities for promising man-machine dynamics research is quite large, and theoretical efforts to date do not display a unifying cohesiveness. Because of this, a research strategy is required for near-term efforts to emphasize current needs and most-promising paths. Initial efforts under the stragegy adopted here will:

- Respond to worst-case mission phases and tasks. Development and research will concentrate on man-machine dynamics problems in which desired system performance is currently most difficult to attain.
- Emphasize the application of human factors design principles and research approaches already known to be effective and productive.
- Ensure broad consideration of the usefulness of new equipment, new design concepts, and new capabilities provided by advances in technology in other areas.
- Comprehensively employ the best available human factors research methods and tools, and incorporate advances in methodology wherever possible.
- Emphasize flexible and efficient utilization of available resources for performing the required research and development.

The following paragraphs discuss these strategy points in more detail and describe the R&D objectives in man-machine dynamics that are related to them.

Several specific mission phases or tasks can be identified that currently place severe demands on pilot and crew and that are most critical in terms of desired overall system performance. These include:

- Rotary-wing, all-weather operations, especially those involving icing conditions, low-ceiling and low-visibility approaches, or approaches and departures involving unusual flight path and speed patterns.

- Nap-of-the-earth operations, especially those conducted during night or all-weather conditions.

- Precise navigation during low-level and NOE operations. Map-terrain coordination, continuous tracking of current aircraft position, specification of ground positions identified from the air, and location of desired map points on the ground are all very difficult crew tasks.

- Target detection, recognition, identification, localizing, and ranging, especially in relation to evasive aircraft maneuvers.

- Weapons selection and delivery, including aiming on-board weapons and controlling fire from other sources.

- Rapid and efficient cargo handling in precise acquisition and delivery operations.

Initial efforts will concentrate on finding practical solutions and simple equipment to permit the successful performance of these mission phases.

In addition to the specific mission segments discussed above, several man-machine interface problems can be identified that are general to all or most missions but that are known to require improved man-machine dynamics. Research efforts aimed at general man-machine integration improvements are required in the following areas.

HANDLING QUALITIES AND CONTROL REQUIREMENTS

In contrast to conventional aircraft, rotary-wing and V/STOL aircraft dynamics pose difficult design problems in specifying handling qualities, stability characteristics, control power, and control implementation. Efficient use of the pilot's capabilities requires a balanced design in this area. He must have the full range of aircraft response capability at his disposal for use when necessary. At the same time, the aircraft should not monopolize his attention and motor response capabilities for routine, repetitive control requirements. General improvements in understanding these factors and their relationships are required to improve pilot/aircraft integration, to ensure adequate aircraft responsiveness to pilot control inputs, to permit precise flight path and position control where required, to reduce pilot skill and proficiency requirements for demanding mission segments, to provide the best possible margin of safety for maximum performance operations, and to reduce pilot control errors. A developed understanding of these factors would also assist in the determination of what degree and what type of automatic flight capability must be provided for achievement of specified mission performance.

PRIMARY CONTROLLERS

Closely associated with the above are problems involving the design and implementation of the pilot's primary controllers: the collective, cyclic, and yaw controls. Technology advances have made possible a variety of new concepts in primary controllers. For specific critical tasks and for man-machine integration in general, various departures from conventional control implementation offer the possiblity of improved precision in translating pilot decisions into control inputs. These include side arm controllers, manual devices for direct rate or direct attitude control, fly-by-wire systems, including fly-through autopilot designs, controls integrated to provide combined pitch-roll-yaw-altitude control, and controls incorporating tactile displays, as well as the more conventional accessory stick-grip switch arrays. Suitable implementations of these concepts could provide increased control precision; reduced pilot manual task loading; reduced effort, response time, and error rates; and reduced unintentional mixing of roll and pitch commands.

CREWSTATION INFORMATION REQUIREMENTS

Problems in the information and display area for crewstation design closely parallel those in the control area. The required information for a given mission is often difficult to specify and many requirements vary with mission phase and mission type.

Information requirements can also be implemented by displays in many ways and progress in the various display areas is occurring rapidly, presenting the possibility of radically new cockpit and crewstation display concepts. The displays in today's helicopter cockpits are primarily adaptations of fixed-wing instruments and displays. They were largely developed for missions and operational roles very different from those planned for future army aircraft; and, in addition, they were developed and standardized at a much earlier stage of development in display technology. Ways must now be found to capitalize on modern display technology to obtain improved system performance, and to do so without sacrificing the reliability, independence, simplicity, standardization, and redundancy that characterize present cockpit displays. The first goal for R&D in the display area is to identify more precisely the information required by pilots and crewmen in the execution of individual mission segments. The mission tasks or functions that should be evaluated to determine information requirements include in-flight mission planning and progress evaluation, flight profile phasing, weapon or cargo delivery, opposition detection and required response determination, aircraft systems status monitoring, power and fuel management, coordination with other aircraft and ground units, and navigation by internal or external references.

DISPLAY IMPLEMENTATION

The second objective for R&D in the display field is to provide new wholistic crewstation design concepts and methods that will display the required information efficiently and effectively. The objective is to achieve more accurate, more reliable, and faster information transfer by providing displays that are easier to use and interpret. Information can be displayed in combined forms and in improved formats to achieve reductions in scan and interpretation times. Concepts such as the pilot-manager approach for highly automated equipment, and the attention management approach for less complex systems, should be fully explored. The most significant problem area is currently high visual task-loading encountered in contour and NOE pilot tasks. Visual displays also pose difficulties for other operations requiring external visual attention and for night operations in which visual dark adaptation is required. Reductions in visual task-loading, better management of limited pilot and crew visual attention, and nonvisual displays should receive careful attention.

DISPLAY INTEGRATION

One of the most promising approaches for improved man-machine integration is the possibility of effectively combining displays with one another and with control devices. Sensible and appropriate combinations of displays can greatly improve information transfer by eliminating mental effort. Similarly, combinations of related displays or displays and controls can make it possible to perform more complex functions. Head-up displays (HUD) can permit, for example, both navigation and attitude control functions to be performed simultaneously. Displays can now be created that integrate the information required for a variety of specific mission functions, that efficiently use available time and capabilities of the pilot, and that more directly translate pilot decisions into control inputs. Developments in the display field that should be evaluated for applicability to Army mission requirements include head-up displays; helmet-mounted displays; and CRT devices for display of FLIR, IR, radar, and LLTV, as well as altitude, navigation, and system status signals. Advanced electromechanical devices for integrated horizontal and vertical situation displays should be explored for application to Army requirements.

OTHER GENERAL PROBLEM AREAS

Several additional general problem areas, less extensive in scope than handling qualities, controls and displays, remain to be discussed. For each area, continued R&D attention can provide improved equipment and better designs giving more effective man-machine integration and better system performance. These areas include communication requirements and implementation for crew coordination, and for aircraft coordination in both the command and control functions, and in the air traffic control functions; flight path prediction and control, especially in relation to terminal guidance problems for internally and externally referenced approaches; the effects of combat damage to equipment and injuries to crewmen in terms of resulting degraded operating modes; the problems of spatial disorientation, which are especially hazardous to helicopter pilots; and the effects of disturbances in sleep-wakefulness patterns that frequently result from operational requirements.

In each of the subdiscipline areas, special emphasis must be placed upon obtaining the maximum results from research efforts by ensuring that all of the available research methods and tools are fully exploited.

The capabilities of new procedures, better experimental designs, and innovative test and measurement schemes must not be overlooked. Modern developments in the behavioral sciences can provide improved observation, recording, and analysis of human performance. Related developments in mathematical modeling of behavior, instrumentation for recording, and electronic data processing of results must be comprehensively employed. Advances in film and video tape image acquisition, for example, offer the opportunity to significantly improve research methodology. Man-machine dynamics problems require (and can significantly benefit from) increased use of simulation techniques and more extensive use of technology demonstration procedures. The use of mockups, dedicated aircraft in subsystem development, advanced field test concepts, and generally complete HF testing throughout system and subsystem development can greatly expedite systematic progress in man-machine dynamics.

The final point of emphasis in the research strategy adopted here places importance on the efficient use of the Army's aviation human factors resources. Numerous organizations have an interest and participate in aviation RD/T&E in the human factors field. Personnel and facilities are found in many locations. A partial list includes The Office of the Chief of Research and Development; the Human Engineering Laboratory; Aviation Systems Command, including both The Directorate for Research, Development and Engineering and the Air Mobility Research and Development Laboratory with its joint NASA-ARMY facilities; and Commodity commands of DARCOM such as MICOM and ECOM. In addition, several field test organizations perform developmental and operational testing both within DARCOM and independently of DARCOM. Systematic progress in the many difficult problem areas of man-machine dynamics will require the most efficient and fully coordinated use of these resources. Thus, new efforts at interagency coordination are required to advance and improve the HF process as well as the technology. Coordinated management, described above, is one of the objectives in making the HF process more effective. The others are more specific goals in streamlining, updating, and improving the methods and practices used to incorporate HF technology into Army systems during development and procurement. Improved methods will be developed for system analysis, task analysis, workload prediction, determination of manpower and crew requirements, the use of mockups and models, and the development of test and evaluation requirements to verify that designs function as intended. Additional process-related methodology improvements will be developed in procedures for test and evaluation and in the effective use of specifications, standards, and other contract-related guidance documents.

The objectives and program elements of the R&D program in man-machine dynamics are presented in chart HF–III.

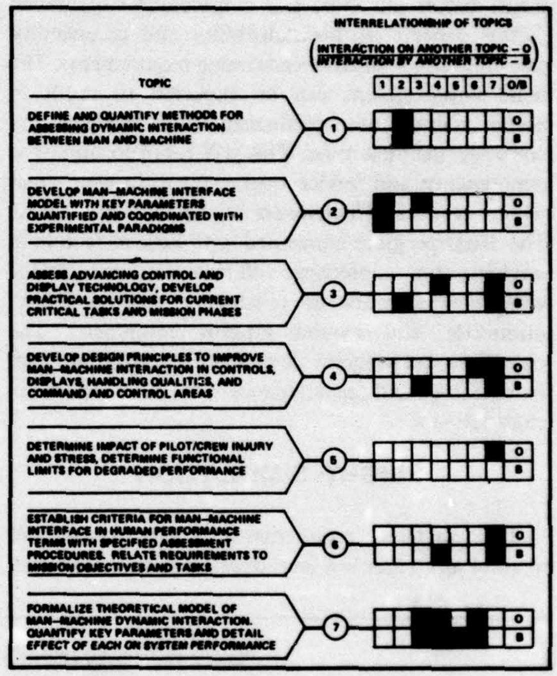


Chart HF–III. Man-machine dynamics.

TRAINING AND MAINTENANCE

System design impacts training and maintenance requirements because these are largely "built-in" when systems and equipment are originated. The costs and importance of these requirements are principle factors in the operation of Army aviation systems. Deficiencies in either directly impact flight safety and operational effectiveness. In both areas the significance of potential improvements requires continued research efforts to increase efficiency in the use of manpower. The objectives of R&D efforts in this area are to reduce training and maintenance requirements, to provide improved procedures for performing training and maintenance, and to increase the effectiveness of training and maintenance aids.

In the area of flight crew training, Army efforts have pioneered the use of simulation and other up-to-date techniques. R&D efforts are required to extend the benefits obtained by these techniques and also to develop crewstation designs and aircraft operating characteristics that minimize training requirements. But training also encompasses ground crew personnel who service and maintain aircraft systems. Here more than anywhere, improved aircraft design procedures, the effective use of built-in test equipment, better job aids, and consideration of human factors aspects of maintainability and accessibility can minimize maintenance training requirements. The same improvements can be expected to result in better maintenance, performed when required and correctly the first time. This will result in improved maintenance and service operations in forward areas where combat effectiveness is directly influenced. The R&D program concerned with human factors in servicing and maintenance will have a strong interface with developments in reliability, maintainability, diagnostic, and ground support equipment. The objectives and program elements of the R&D program in training and maintenance are summarized in chart HF–IV.

FLIGHT SIMULATION

The mission requirements trends toward all weather and night low-level operations have extensive implications for the nature of technology base research as well as the development of new engineering methods and the validation of proposed system designs. Increases in the cost, complexity, and sophistication of necessary R&D have swept through all of these areas. Many sources have recognized a vital part of the answer to these problems will be increased use of flight simulation as a research and development tool. Planning for the development of this capacity, a research and development simulator for low-level all weather helicopter operations, is now underway in AVSCOM. When an effective capability to simulate nap-of-the-earth helicopter operations and other current mission requirements is finally available, significant issues in both technology base R&D and in system development support can be resolved. Simulation will provide fundamental knowledge in human engineering, flight controls and other basic technologies as well as trade-off information for use in system design. It can be employed to originate, demonstrate and validate system design methods and engineering criteria. The benefits will include a capability to evaluate system and subsystem hardware before significant army commitments have been made. It will permit the development of a new spectrum of cockpit and control system hardware, new research and engineering methods, and validated criteria and test techniques all matched to the new and demanding air mobility mission environment.

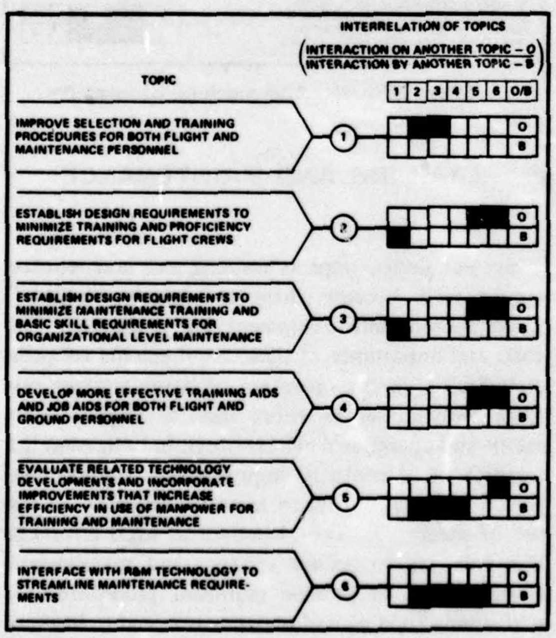


Chart HF–IV. Training and maintenance.

The speed, safety, and economy with which these benefits can be realized by strategies based on simulation R&D are the positive side of the picture. But an advanced research simulator with high versatility and sufficient helicopter mission modeling power to permit valid forecasts of real system performance is an expensive and complex system, itself. Current problems here center on the design and development of a new simulator which will meet the R&D objectives, and on the development of specific plans, procedures, and strategies for its employment. To a major degree, the visual display system performance requirements for low-level helicopter mission simulation are unknown. Field of view, detail resolution, scene detail content and dynamics for simulating NOE flight and mission tasks remain to be determined. The best technology for such a facility (e.g. TV, terrain models, computer imagery, laser-based displays, etc.) is also not immediately evident. Other design choices in terms of motion system performance, computer control equipment and cockpit versatility remain to be determined as well. Resolution of these questions may require human factors

research on sensory and orienting mechanisms for aircrew tasks.

The detail design of a research simulator also depends heavily on the purposes to which it will be put. This calls for extensive planning and review of potential research to establish topics, variables, subjects, hardware and software to be employed and which together impact simulator system requirements. This effort is now underway in the areas of flight control technology and human engineering technology. Both will be major users of the new capability. Similar planning will need to be performed to cover system engineering and product manager support applications of this new R&D capability.

Objectives and program elements in developing the new flight simulator research capability are summarized in chart HF–V.

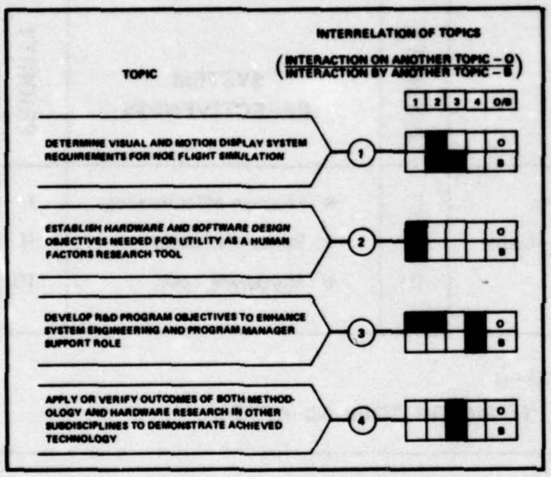


Chart HF–V. Flight simulation.

[illegible]

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the human factors discipline, The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

Broadly stated, the main objective of human factors (aviation human engineering) is the initiation of specific basic and applied behavioral research projects to fill current technology gaps which most significantly impact operational mission requirements and system costs. These problem areas center around high operator visual and auditory task loading during all types of terrain flying; visual requirements during night and adverse weather operations for flight, navigation, target acquisition. and weapons delivery functions; cockpit control and display requirements for the levels of man-machine integration required by the new spectrum of adverse weather, night and precision cargo operations; and the definition of simulation capabilities required to provide a useful simulator for engineering research and development.

The near-term goals supporting this main objective and based on the previous technological discussion are identified as follows:

- Develop and expand the usefulness of the concept of workload. Pilot and aircrew workload or task loading should be elevated to the *status of a research variable* and engineering parameter by the development of reliable measurement procedures applicable to cockpit tasks in general. Standardized and general measurement procedures should lead to accurate modeling and predictive capabilities.
- Initiate development of non-visual and non-auditory cockpit display devices to permit information transfer capability with reductions in visual and auditory task loading.
- Develop an economic model of pilot attention based on GPSS–V or other suitable computer simulation capability. The model should provide rule-of-thumb or figure-of-merit outputs concerning pilot workload based on cockpit interface properties and mission requirements inputs. Refinements of the initial effort should serve as a research tool leading to advances in engineering procedures for man-machine interface design.
- Obtain more complete information on visual task requirements and stimulus properties prevalent in terrain flight operations, especially

night and adverse weather operations. The stimulus conditions and visual task requirements of target acquisition for the characteristic range of mission conditions should also be more fully explored. Available information should be compiled and supplemented where necessary by new research. The effort should lead to a summary of relevant data in a format suitable for describing and predicting visual performance requirements of aircrew members and visual display functions and requirements for visionic devices. This information should also provide a data base for the determination of simulation requirements for a research simulator to study terrain flight and night operation.

PROGRAM PRIORITIES

General. Table HF–A presents, in a prioritized listing, the human factors technology subdisciplines, vehicle subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technological Subdisciplines. Subdisciplines in human factors are basically divided between scientific and engineering activities and are represented by the major topical areas as shown in table HF–B.

TABLE HF–A
PRIORITIZED HUMAN FACTORS OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Engineering psychology	I	• Cockpit work-stations	I	• Mission effectiveness	I
• Human factors engineering	II	• Maintenance work stations	II	• Personnel costs	II
		• Support facilities	III	• Hardware costs	III

TABLE HF–B
HUMAN FACTORS SUBDISCIPLINE MAJOR TOPICAL AREAS

SUBDISCIPLINE	MAJOR TOPICAL AREA
ENGINEERING PSYCHOLOGY	• Basic and applied behavioral research. • Human Performance Technology. Sensation & Perception, Psychomotor skills, Learning, Physiological behavior, etc. • Man Machine Dynamics Mock-up, Simulation & Flight Testing of man-machine integration and performance.
HUMAN FACTORS ENGINEERING	• Procedures applied from pre-design through deployment. • Static and dynamic workstation design requirements. • System analysis, including function, task & time line analytic procedures. • Policy and guidance documentation including regulations, specification contracts, standards and handbooks. • Test and evaluation in mock-ups through Field Trials.

Vehicle Subsystems. Vehicle subsystems, as related to human factors technology, are divided for consideration into aircrew and groundcrew workstations. In this orientation, each aircraft worksite where maintenance is performed is regarded as a maintenance workstation. Emphasis on the man-machine is the main point of this breakdown. In the cockpit areas display, control, and communication equipment have the primary dynamic man-machine interface requirements; whereas environmental control, personnel equipment, and crewstation layout/anthropometry emphasize relatively static man-machine relationships. The final category, Support Facilities, refers to software, hardware, and support facilities which are not aircraft components but which are required to complete the aircraft-based weapon system. Important elements range from the information available during mission planning to the test stands, equipment, and field manuals employed during maintenance.

System Effectiveness. In the area of system effectiveness the usual speed-weight-power type of performance parameters have been deemphasized in favor of operability objectives which emphasize the quality of the man-machine interface. This is not to say that hardware performance is unimportant, but merely that it will be treated elsewhere; and that emphasis here is on the man-machine interface. The most important objective is to meet the mission objectives without creating excessive aircrew workloads. To provide for the contingencies of combat, some degree of aircrew mental and physical capacity should be available as a reserve over the normal mission requirements. Another important objective is to improve mission effectiveness in night and adverse weather conditions. Ideally, operational capability should be raised to the level of clear day operations and an expression of mission capability as a ratio of clear day effectiveness may prove useful in defining how well this goal is met for specific light and meteorological conditions. Flexibility of utilization refers to the vehicles adaptability to varying tactics and mission assignments within its design role. Helicopter weapon systems should fully capitalize on the inherent operational flexibility by providing rapid response times, easy shifts in mission types, adaptability to varying tactics and the ability to shift mission objectives even during mission execution. Overspecialization of equipment to achieve mission capability objectives can reduce adaptability and this should be prevented in the man-machine interface design. The remaining system effectiveness objectives emphasize personnel and hardware costs. Systematic attention to each of these areas is warranted to obtain improvements in system performance and reductions in system cost.

Priorities. With reference to table HF–A, the human factors subdisciplines, vehicle subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority. Since all of these categories and objectives are important, priorities should be regarded as suggestive rather than as absolute. Even with this degree of looseness in the assignment of priorities, several horizontal "tensor" relations can be usefully extracted from the table. Insertion of subcategories in each tensor can describe or suggest virtually every type of human factors research and development effort with regard to approach, topic, and objective.

MAJOR THRUSTS/RATIONALE

The major R&D thrusts pertaining to the human factors technology are:

- Develop behavioral measurement procedures applicable to the general case of man-machine interaction to characterize workload resulting from task and cockpit equipment combinations. Employ these procedures to model and predict workload to insure adequate mission workload reserves.
- Perform psychometric studies, simulation and flight testing necessary to support development of non-visual, non-auditory cockpit display devices to reduce sensory workload and to improve night and adverse weather capability.
- Develop a computer model of pilot performance as a research tool to relate cockpit workstation and task elements to aircrew workload. Verify and improve the model to permit assessment of cockpit workstation and mission tasks on crew workload, night and adverse weather capability and flexibility of utilization.
- Assess visual task demands and stimulus conditions encountered in night and adverse weather conditions to define man-machine interaction requirements and cockpit vision equipment performance requirements to provide required mission flexibility, workload reserve, and night/adverse weather capability.

All of these major thrusts are high priority "tensor" combinations, directly impact the important

mission effectiveness goals which are man-limited, fall within AMRDL's research and development area of responsibility and represent significant technology voids in which high returns are possible for modest investment of resources.

LABORATORY PROJECTS IN AVIATION HUMAN ENGINEERING

INTRODUCTION

The research described below for FY77 marks the beginning of aviation human engineering (human factors) R&D within AMRDL. Preliminary efforts to date and projects during FY76 have concentrated on coordination of plans and programs with other Army agencies concerned with human factors engineering in aviation, and on problem and approach definition for new efforts that have high payoff potential and represent aircraft development technology requirements specific to AVSCOM mission areas.

This is an exploratory development (6.2) effort conducted primarily by AMRDL Ames Directorate at Ames Research Center, Moffett Field, California.

DESCRIPTION OF PROJECTS

Aviation Human Engineering. Project 1F262209AH76-TA XI is an exploratory development effort to conduct a comprehensive and systematic program of behavioral research leading to improved methods and criteria for both design and test of Army air mobility vehicles and systems. The development of aviation human factors technology will provide accurate prediction of design requirements and effective test verification procedures for Army airmobile mission requirements. The new methods, criteria, and understanding of man-machine interactions resulting from this technology will allow more effective use of aircrew skills and capabilities, improved man-machine integration, and will enhance the performance of operators as elements of airmobile systems. The approach involves coordinated analytical and experimental investigations utilizing laboratory tests, ground-based and in-flight simulators, mathematical modeling and model verification, and flight test investigations.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the human factors R&D efforts as presented in the technical disucssion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 human factors FY77 R&D effort is $280,000 and represents 1% of AMRDL R&D 6.2 funds (excluding Project 1F262201DH96 Aircraft Weapons Technology funds).

INTRODUCTION

TECHNOLOGICAL DISCUSSION

AIR MOBILITY

LASERS

RADAR

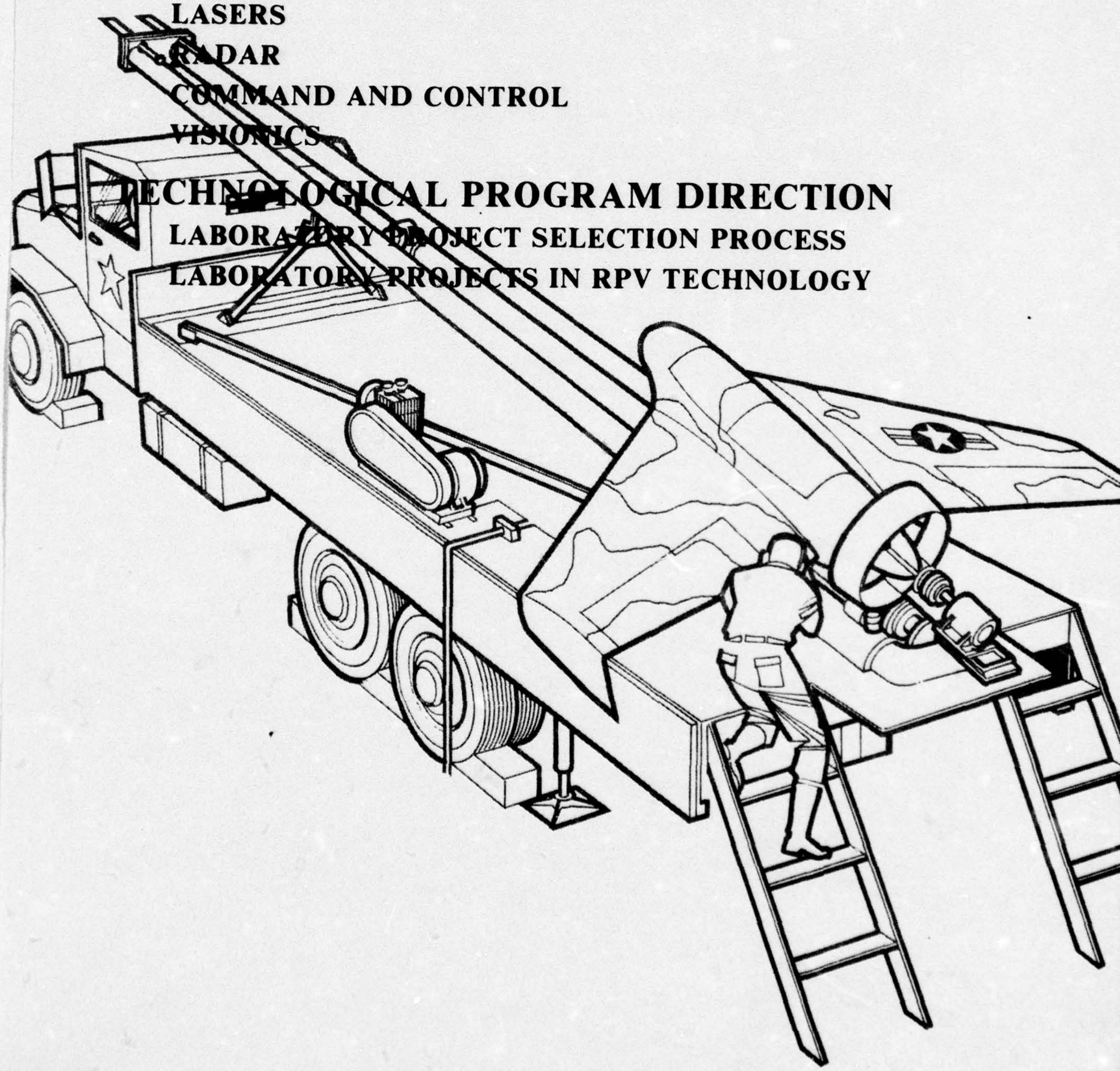
COMMAND AND CONTROL

VISIONICS

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS IN RPV TECHNOLOGY



INTRODUCTION

Exploratory development efforts for Remotely Piloted Vehicles did not exist within AMRDL before FY76. Other laboratories, such as NVL and CSTA Laboratory, had mission programs that constituted a base for their RPV efforts, but AMRDL essentially did not. These baseline laboratory mission programs are now being consolidated and oriented toward RPV applications.

Many technological voids currently hamper the development of mini-RPVs (less than 200 lb) for military applications. The primary areas that need improvement are: air mobility, lasers, radar, command and control, and visionics. The term air mobility (as used here) encompasses many key disciplines necessary to the development of mini-RPVs – propulsion, launch and recovery, survivability, RPV configuration optimization, and structures. Laser developments emphasize rangefinders/designators that are smaller, lighter, brighter, and have duty cycles higher than lasers currently available. Radar is seen as a payload to extend mission capabilities into all-weather applications by providing fixed target enhancement, moving target indication, and high-resolution ground mapping. The fundamental deficiencies of currently available command and control equipment are that the RPVs must be operated in line of sight of the ground station, only a single RPV is aloft at a time, and little or no jamming protection is provided. The Army needs equipment to provide anti-jam protection for multiple RPV operations out of line of sight of the ground control station. Visionics efforts focus on two areas: TV and thermal imaging. Major emphasis is being given to reducing cost, weight, and band-width requirements consistent with RPV requirements.

TECHNOLOGICAL DISCUSSION

AIR MOBILITY

PROPULSION

Propulsion system technology for RPVs provides the mechanisms and processes by which the chemical energy in fuel is converted into forward thrust and/or lift and the required electrical energy to operate the RPV payload. The effect of the propulsion system technology on the aerial vehicle is profound. The performance, endurance, and reliability of the vehicle depends almost totally on the availability of the required power and how efficiently this power is converted to lift and/or thrust. The unique mission requirements of the RPV demand that the propulsion system deliver maximum horsepower/weight ratios, low levels of vibration to ensure adequate structural reliability, low noise and IR signature to reduce detectability and vulnerability, and low fuel consumption to ensure long range.

RPV propulsion systems are normally considered to include a powerplant (engine), an alternator (to convert mechanical energy from the engine to supply engine and payload electrical requirements), and a thrust producer (propeller or, for a rotary wing RPV, a rotor). However, market surveys of suitably sized powerplants, thrust producers, and alternators reveal the following:

- Currently available engines in the horsepower range of interest (nominally 5-60 horsepower pending finalization of RPV mission requirements) are unsuitable for application to RPVs because of one or more of the following:
    - Vibration characteristics
    - Reliability
    - Performance (high fuel consumption)
    - Low power/weight ratios
    - High noise levels
    - High cost
- Although some research of small propeller technology has been conducted (primarily for the model airplane industry), these propellers must be optimized for RPV applications.
- Off-the-shelf alternators are too heavy and bulky for RPV applications.

To overcome these deficiencies, research and development efforts are planned to provide the propulsion system technology required to support Army RPV mission requirements. Although these requirements have yet to be finalized, sufficient information has been gathered on existing hardware applicable to RPVs to indicate that these research efforts should be concerned with achieving near-, mid- and long-term objectives.

The near-term objective of planned and on-going research is to provide the Army with a suitable RPV propulsion system, albeit with limited capability, to incorporate into the Army's first RPV aircraft. The time available to satisfy this requirement precludes the development of hardware designed specifically for the RPV aircraft. Therefore, achievement of this near-term objective will hinge on modifications to existing hardware.

Existing candidate engines include commercially available engines (generally two-stroke engines, although some four-stroke and rotary piston engines are available). None were designed for flight vehicles and, as a result, none demonstrate acceptable noise, vibration, reliability, weight, or performance levels. Modifications to these engines will consider twinning of the 2-stroke engines, variations in materials, more sophisticated fuel handling, ignition systems and cooling schemes, and de-rating to achieve reliability. Commercially available alternators will probably be acceptable for near-term RPVs and modifications will be limited to installation-related adaptions. Propellers are considered to be the prime thrust producer for near-term RPVs, although research and, therefore, progress in RPV-sized propeller technology has been at a low level.

Cost is a major consideration in the development of RPV propulsion systems. The use of existing technology to satisfy near-term objectives, although conceptually inherently less expensive that the development of new propulsion systems, is more than offset by the cost of the extensive modifications required to develop suitable systems.

The mid-term objective of the RPV propulsion efforts is to develop advanced RPV propulsion systems for the next generation of Army RPVs. These systems should be developed solely for application to the RPV mission requirement. Significant advantages in weight, vibration, performance, and reliability should be possible with this approach. Primary emphasis will fall on the development of small piston engines and rotary combustion engines since, at this time, they represent the most viable alternatives. Designs will be subjected to extensive cost analyses relative to acquisition and operation. Thrust producers for these propulsion systems will be optimized based on RPV engine performance and mission definition.

Long-term objectives of RPV propulsion research will be to define Army RPV requirements. New concepts of RPV propulsion will be investigated, including the application of turbines, turbo fans, and other propulsion systems. Research will be aimed at extending the operating envelope relative to altitude, speed, and environmental conditions.

LAUNCH AND RECOVERY

The Army is confronted with the necessity to launch and recover (L&R) sophisticated and expensive mini-RPV systems from unprepared sites in forward areas, it is evident that any equipment necessary to launch or recover such RPV systems imposes a burden on the units that operate these systems. Lightness, simplicity, mobility, and reliability are some of the modifers that describe the improvements needed in RPV L&R operations.

Although the ideal RPV would be one that requires no L&R equipment, it must be emphasized that it is rarely possible to meet all situations. Any airborne vehicle is sensitive to weight constraints and the tradeoff between complexibility, weight, and cost, and mission requirements is not decided by a single factor. Systems that result from these tradeoffs will have to be a compromise between competing requirements.

The present launch system weighs over four times the gross weight of the RPV and has very little weight in the airborne vehicle; the present recovery system weighs over five times the gross weight of the vehicle and requires about 8 percent of the weight of the airborne vehicle for the recovery system. See figure RV–1.

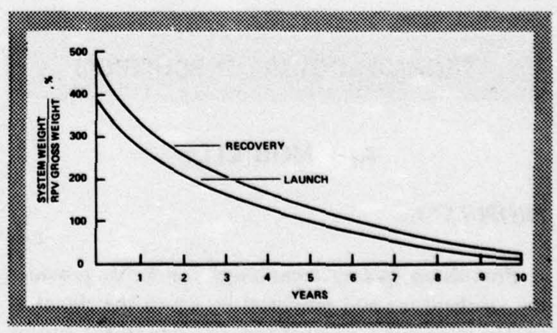


Figure RV–1. Forward area tactical systems.

The anticipated goals would be to reduce all these factors by an order of 2 within two years and by an order of 4 in five years.

Existing L&R systems are designs that do not fulfill the current tactical needs. Most launchers are some form of rail with a power boost (such as steam or compressed gas). They generate very large static and dynamic forces and the result is large, heavy structures to withstand the loads.

The two-year time frame for a 50 percent reduction in the weight of a launcher is achievable through the use of more efficient structural materials and more efficiently integrated power boost for the RPV. A composite, filament wound, or tetrahedron structure for the basic launch frame should achieve this goal; power assist from such items as superheated water or other chemical processes can probably surpass the 50 percent reduction.

Efforts to improve this power boost system beyond this point would have only slight returns. The next step for mid-term improvement will be through other types of launch systems. Circular takeoff trajectories, balloon release or assist, auxiliary lift devices are all areas that deserve exploration for solutions in the launch area. Launch systems will eventually have very small power and weight requirements and may either be totally integrated with the RPV or be available for other functions in the field.

Recovery is presently cumbersome and requires large areas for employment of vertical and/or horizontal nets, arresting equipment, and low-angle approach paths. In forward areas, this system would be easily located by the enemy, thus requiring much time and effort to set it up, maintain it, and camouflage it. Suitable areas for deployment are restrictive, making operation in mountainous and swampy areas infeasible.

Recovery systems can be designed which need not be emplaced in the ground or used in special areas. Such techniques as single wire balloon recovery, high lift devices such as para wings or split wings or stowed rotors, low-pressure air inflated structures, or circular landing trajectories can achieve 50 percent or greater near term reductions. The foregoing techniques are not sufficiently developed for near term use, but should be available as mid-term solutions. Far-term solutions should have only small percentage impacts on the RPV and recovery system by use of rotors, advanced high lift technology, retrofire assisted systems, and other deceleration devices.

SURVIVABILITY

The primary objective of survivability is to formulate concepts and to develop means for providing an RPV with an inherent low detectable signature. This approach degrades or denies target acquisition by enemy weapn systems that use the aircraft signature characteristics for surveillance or guidance. RPVs may be identified and acquired as targets by techniques ranging from unaided visual and audible detection to highly sophisticated optical and electronic sensing.

Countermeasures against threat systems can involve reduction of the RPV signature, or use of an efficient combination of both signature reduction (passive countermeasures) and deception (active countermeasures). Ideally, passive countermeasures are designed into the RPV at minimum penalty. Signature reduction, which is normally broadband, is effective against a variety of weapons. The subtechnical areas discussed under this subdiscipline are defined in table RV–A.

Significant low-penalty broadband reductions in radar cross section (RCS) can be made in the design of RPVs by shaping and carefully applying radar-absorbent materials. Shaping studies have shown that basic reductions in RCS are possible and analysis is required to define structural tradeoffs such as shape, cost, etc.

The survivability contribution of RCS reduction against the current known threat is being assessed. Experimental hardware evaluation of this assessment may be required. Continuing analysis of existing and anticipated threat radar systems is required to determine the most effective approaches for countermeasures. Investigations of radiation characteristics, methods for predicting radiation levels, and methods or techniques for reducing radiation have been completed. Basic techniques are available to apply to RPVs and to reduce or eliminate any significant sources of radiation. A continuing emphasis, as technology changes, is required in the following areas:

- Application (scaling up or down) of existing IR suppression technology.
- Improved definition of threat weapons characteristics to properly assess countermeasures capability.

TABLE RV–A
REDUCED DETECTABILITY SUBDISCIPLINE DESCRIPTION

ACOUSTIC	• Pertains to definition of radar reflectivity (echo) of RPV systems. Selection of echo reduction in relation to threat system and deployment.
VISUAL	• Pertains to definition of IR emissions from engine and RPV systems. Application of reduction techniques and hardware design is based on threats analyzed for required countermeasures.
INFRARED	• Pertains to the investigation and definition of RPV features that provide significant visual detection cues. Concepts and techniques are developed and field evaluated.
RADAR	• Pertains to the definition and measurement of acoustic signatures, analysis of noise reduction, and survivability effects.

- Improved analysis procedure to evaluate missile and RPV engagement and to determine the probable level of survivability.

Generally, visual countermeasures against an optical tracker or weapon aid are rather limited. Target characteristics that can be used for tracking are: contrast the background, point-to-point contrast across the target, and active lights on the target. Recently completed visual detection investigations show that the mechanism of detecting targets at ranges up to about 1-1/2 km by the unaided eye are primarily attributed to:

- Sound
- Motion
- Color
- Size

Any one characteristic is sufficient for detection. The important visual detection cues in the 1-1/2 to 3 km range are:

- Sun reflections
- Fuselage shape
- Motion
- Contrast

At ranges greater than 2-1/2 km, color and pattern have an insignificant influence on visual detection, provided it is not in sharp contrast to its background. A variety of paints have been developed to reduce visual contrast and to provide required IR reflection characteristics. These paints are available to provide the RPV with the best combination of visual contrast reduction and resulting in visual detection.

The worth of attaining reduced aural detection distance through reduced noise levels must ultimately be assessed by a survivability payoff. Noise provides warning of an approaching target, thus increasing the time available for readying optically sighted weapons. Where direct line of sight is not available to optical weapons, the noise signature usually provides warning. Recent studies of visual detection show a marked decrease in visual acquisition ranges when the aural cue is missing. The various areas of research pertaining to survivability through reduced detectability which are required are summarized below:

- Evaluate previous RPV development concepts for reducing radar cross section and review previous field-measured RPV radar tracking data and determine the best potential configuration for future development of RPV vehicles.
- Conduct radar systems tracking angle error analysis for a variety of representative RPV radar cross sections for threat radar systems of interest. Determine from these data the required effective RCS for RPVs.
- Conduct any required radar tracking field tests to verify RPV survivability requirements that cannot be determined by analysis.
- Design, fabricate, and test advanced concepts of low radar cross section to provide off-the-shelf technology for new mission systems.
- Apply available low reflectivity paints for evaluation during field testing to determine the best for future operational use.

- Apply available IR suppression technology to candidate RPV configurations to provide maximum IR radiation suppression.
- Design, test, and verify when required conceptual systems to minimize IR emissions from candidate RPV configurations.
- Define detectable criteria and conduct detailed analysis of operational conditions to determine recommended noise levels for a given survivability level.
- Support development of propulsion systems for reduction of noise to obtain recommended aural detection criteria.

Vulnerability reduction, another feature of survivability, provides protection for RPVs against ballistic projectiles and antiaircraft missiles by airframe application of materials and design techniques derived through research investigations. Vulnerability reduction technology is intended to increase RPV airframe survivability by minimizing the consequences of damage caused by projectile hits. It includes reducing probability of attrition (crash), forced landing, and mission abort. Significant projectile threats include all known explosive projectiles launched from infantry rifles through automatic cannon, contact fuzed shell, as well as the fragmentation and blast effects of larger ballistic or guided weapons. The mechanisms of kill included fire blast penetration and all other means of failing and degrading the critical functional systems and components of aircraft including structure, fuel, flight controls, propulsion, and mission equipment.

Areas of research required to develop technology reduced RPV vulnerability to combat damage are summarized below:

- Investigate "soft" structural material concepts that will provide minimum structure damage from ballistic hits and maintain airframe structural requirements.
- Develop concepts for local lightweight hardening shells to protect critical control components from fragmentation projectiles.
- Perform ballistic tests of candidate RPV structures designed to minimize ballistic damage.
- Identify the major vulnerability contributors of each RPV system and suggest design changes for improvement.

RPV CONFIGURATION OPTIMIZATION

The Army currently has extensive research, analytical and test efforts underway to determine if RPVs can supplement other air and ground means for obtaining intelligence information and directing firepower. The configuration of the RPV can greatly impact the cost effectiveness of the overall system. Depending on performance requirements (such as speed, maneuver, and endurance), a number of configuration approaches may prove to be optimum from size, weight, fuel, and cost considerations. A parametric design study, covering a wide range of design and performance variables, will be used to identify promising vehicle configurations and establish a data bank to provide the base for the rational definition of RPV system requirements.

Many RPVs constructed in the past have been large, high-speed jet and rocket-propelled vehicles. The present state of the art in small jets indicates a present lack of small jet engines, with little likelihood of obtaining the low fuel consumption values required. Thus, small RPVs will rely on small reciprocating engines. Propulsion systems will use either propellers or ducted fans.

Sufficient aerodynamic data appear to be available for prediction of vehicle lift and drag characteristics, although correlation is necessary. Pitching moment effects at lower Reynolds numbers indicate problems occur at high lift coefficients. Sudden excursions into instability regions have always been indicated at low Reynolds numbers on wind-tunnel models. These pitching moment characteristics do not occur at higher Reynolds numbers. The judicious use of fences has been known to provide a solution to the problem.

Propeller performance at the small diameters required by RPVs does not lend itself readily to conventional methods of propeller performance prediction. Research and correlation in this area are needed. Better methods for predicting the performance of small-diameter ducted propellers are required.

The differences in characteristics of wings of low Reynolds numbers are sometimes opposite in effect to those known to improve wings at larger Reynolds numbers. Stability and control characteristics due to these differences cannot be predicted by conventional aircraft design methods. Wind-tunnel tests and free-flight tests would be highly desirable.

RPVs, because of their light weight, low wing loadings, and low inertia, are very susceptible to gust effects and wind variations. To maintain control and heading particularly, attention must be paid to static stability and low-speed characteristics. Tailless vehicles with medium aspect ratio wings have high gust sensitivity. Low aspect ratio delta-wing platforms, such as used on high-speed, low-altitude aircraft, have low lift curve slopes and therefore are relatively insensitive to gusts, may be particularly applicable to RPV designs. Thus it would appear that delta or low aspect ratio wing platforms yield the most favorable stability and control characteristics for RPVs.

Research is needed in the study of the variations of aerodynamic effects at the low speeds, small chords, and correspondingly low Reynolds numbers of RPV configurations. Sufficient data can be correlated to provide a good base for performance estimation. Propeller performance, in the small sizes required, must be studied, including fixed pitch, two pitch, and variable pitch designs. Compilation of engine data, including fuel consumption, is also necessary. Definition of the following parameters is needed: ranges of payload size and weight variation; power requirements; endurance and range variations; cruise, dash and minimum speed variations including takeoff and recovery speeds; wing loading; planform and aspect ratio variations; and stability and control requirements. Parametric design study limits will be ascertained so that a matrix of design parameters and conduct parametric studies can be established.

In summary, a wide range of vehicle configuration will be analyzed against a matrix of mission and performance requirements. Effects of various vehicle concepts, wing planforms, wing loadings, and propulsive concepts on vehicle size, weight, power, and fuel requirements will be defined and optimum designs identified for a range of mission requirements.

STRUCTURES

The RPV structural components program will provide a lightweight, low-cost RPV airframe suitable for mass production. The airframe will utilize advanced components technology and will draw on knowledge and experience accumulated from previous work in Army airmobile systems. Testing will be performed to verify the applicability of the materials and techniques to RPVs. In FY77, the best material/technique combinations will be selected for future AQUILA RPV production. This construction technique will be subjected to extensive tests. Applicability of composites to various fixed-wing RPVs other than AQUILA will be investigated, as will fabrication and testing of blades/prop.

Several candidate construction materials and techniques offer significant possibilities of lightweight and low cost for RPV airframe construction. The lightest material appears to be a wet filament wound foam sandwich. This material, which can be used both for outer skin and for spars, can be mass-produced at low cost. Another candidate material is 0.040 in. perforated plastic sheet for outer skin in combination with a wet filament wound spar. It appears that the outer skin could be either vacuum formed, rotationally molded, or blow molded. Several types of perforated plastic sheet could possibly be used for the outer skin, depending on a tradeoff analysis of strength, rigidity, weight, and cost. In all cases, the outer skin would probably be covered with a sheet of 0.001 in. mylar to cover the perforations in the 0.040 in. plastic sheet. Another construction method is hand lay-up. However, this method is not suitable for mass production. Weight penalties and quality control problems are other hazards with hand lay-up.

LASERS

The laser program will develop a second generation laser designator/rangefinder for airborne applications. These equipments will utilize advanced laser technology and would offer advantages over current systems including modular design, commonality to other Army laser systems, lower weight, and higher brightness. The system resulting from this effort will be a tri-service coded, high duty cycle designator/rangefinder. The program is based on a current CSTA mission-funded program wherein Hughes Aircraft Company is fabricating a laser transmitter that combines their conductively cooled laser pump cavity with an ECOM developed unstable resonator configuration.

RADAR

The main emphasis of the radar supporting technology program is to improve performance of components for the development of brass board radar demonstration model, which will weigh close to 400 lb as compared to the required 35 lb RPV radar.

One element of this radar program will provide a light-weight, low cost combination transmitter-receiver for the mini-RPV millimeter surveillance

radar. The present transmitter-receiver module with its power supply and modulator accounts for a large part of the weight of the brass board radar. This element requires the development of such millimeter components as balanced mixers, circulators, and component transitions. Without these components, the transmitter-receiver cannot be integrated into a common module and hence the lightweight 35 lb radar cannot be achieved.

Systems analysis efforts will provide the background data necessary to ensure that the prototype millimeter radar and the 6.2 technical support efforts (transmitter-receiver, components, data processing, antenna development) will mate in reducing the radar weight to 35 lb. Initial efforts will include: investigation of data link requirements to be compatible with the ICNS being developed for the RPV, required waveforms and transmitter-receiver characteristics.

Another element of effort is antenna development. The brass board millimeter radar being fabricated for the feasibility demonstration has a 20 in. antenna producing an 0.43° azimuth beamwidth. Inspection of the AQUILA indicated that a nose-mouth antenna would have to be smaller, thereby increasing the azimuth beamwidth and reducing the radar's azimuth resolution. The antenna development effort will emphasize new approaches to produce an antenna compatible with the AQUILA or any future vehicle. A prime prospect could be a combined electronic-scanned array with a limited mechanical scan. This could drastically reduce the gimbal size and weight. It is envisioned that the antenna will be a line source of some type. The antenna development effort will include the research and development of the antenna element, means of obtaining dual polarization, the necessary millimeter wavelength phase shifters, distribution networks, and beam-steering techniques.

The development of an on-board processor will provide the necessary data compression for mating to the existing RPV data link. These techniques will be employed to send the radar surveillance data to a ground-processing station where target information will be extracted. Data from the millimeter radar flight test will be available for use in determining many of its characteristics. This effort will result in a small, low cost, lightweight on-board data processor that can be used to obtain the desired end product, a 35 lb millimeter radar sensor.

Under the CSTA mission funded SOFTAR program, techniques are being investigated for detecting and recognizing fixed targets at long ranges from helicopter platforms. By use of ground processing analysis the ongoing SOFTAR efforts can be expanded to cover stationary target detection by means of RPV-borne millimeter radars. This requires additional target and clutter signature measurements at 95 GHz analysis of signature data obtained at the higher frequency and higher depression angles, and some further algorithm and processor development.

COMMAND AND CONTROL

Command and control, as used here, refers to the uplink to the RPV from the ground control station and the downlink, comprised of video and telemetry information. Advanced command and control systems should provide the user with an antijam and multiple control capabilities for mini-RPVs. To provide an interim capability in the shortest period of time, two parallel approaches are necessary. The near term data links Integrated Communication and Navigation System (ICNS) will provide a line-of-sight capability with anti-jam protection necessary to operate against the jamming threat out to ranges of 20 km. The ICNS is an advanced development program. Final packaging of the ICNS will be determined for the 6.4 models after completion of a size/weight vs. cost tradeoff analysis. The 6.3 ICNS effort will produce feasibility models for flight demonstration of the antijam line-of-sight, multiple-control capability first at C-band, and then at J-Band. The models will weigh approximately 19 lb. During 6.3 effort, costs required to develop 10 and 15 lb engineering development models along with production cost estimates for each version will be established.

The long-term solution to the data link requirements for RPV is based on a wideband frequency hop concept and addresses the problems associated with the beyond-line-of-sight mission, reduced radio frequency intercept profile (both of the ground station and RPVs), improved anti-jam capability, advanced RPV sensor packages, frequency assignments, overcoming multipath problems, and cost reduction.

The fast frequency hop effort is an outgrowth of ARPA exploratory developments and more recent CSTA mission funding (DH–93). The 6.2 efforts shown will be funded both by mission (DH93) and RPV technology (AF34) funds. The system concept feasibility effort will be conducted during FY77 and FY78, resulting in demonstration of concept feasibility in early FY79. A 3-year advanced development

effort will be conducted during FYs-79, 80, and 81, leading to a flight demonstration of a beyond-line-of-sight system. Continued exploratory technology efforts through 1983 will concentrate on development of wideband microwave power amplifiers, antenna techniques, multipath processing, and bandwidth reduction techniques required for the systems needed for a 50-km mission.

VISIONICS

Visionics is the use of electronics to enhance vision. The application of visionics to RPVs is primarily directed toward television and thermal imaging sensors, and is being managed by the NVL.

Two new programs which will adapt television equipments to RPVs are a day/night solid-state imager program and a cost/weight reduction program for stabilized TV systems.

Devices based on charge transfer device technology charge coupled devices or charge injection devices (CCD or CID), are envisioned as a television type approach to low cost day/night imaging. As daylight charge transfer device technology grows, it should permit low light level operation as well as daylight capability from the same camera system. Based on general laboratory work in solid-state imagers and image intensification, an exploratory development day/night camera program was started in FY76. This program led to the design of a camera based on a focal plane density of about 200,000 elements and a demonstrator camera fabricated with a reduced number of imaging elements. The advanced design will be selected and integrated into an RPV stabilized platform and will subsequently be available for test and evaluation as charge transfer devices are fabricated into larger arrays, the imager will be upgraded to provide higher resolution and better low light level performance. Stabilized television systems currently available for mini-RPVs should perform well but are too heavy and costly. Cost and weight reductions are driving factors, hence technology will be utilized in the construction, i.e., plastic option, composite fiber structures, modular assembly for ease of fabrication, and interchangeable receivers for mission and cost flexibility.

Programs oriented to the adaptation of thermal imaging sensors to RPVs include a pyroelectric vidicon and a 3 to 5 μm thermal imager.

A pyroelectric vidicon detector is a low cost, and lower performance, approach to thermal imaging. Design goals are 2 km detection range and approaching 1 km recognition for a tank size target. An exploratory development model, based on general laboratory technology, was initiated in FY76. This program will lead to a flyable brass board design in FY77 using a TGS or DTGFB vidicon target tube. The camera will be upgraded and further refined with a reticulated target tube and chopping with inversion processing added and may be integrated into a stabilized AQUILA RPV platform for evaluation.

A 3 to 5 μm thermoelectrically cooled thermal imager is based on an outgrowth of night vision laboratory support in this technology on focal plane arrays, coolers, and rifle sight type systems. By FY78, this technology should support exploratory development of a FLIR sensor with performance approaching cryogenically cooled systems for some applications (not targets, shorter ranges).

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the RPV technology discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The program objectives for FY77 are projected as follows:

- The 15-25 HP engine R&D program will provide the propulsion system requirements to meet the next generation of airframes envisioned for mini-RPV. The prime purpose of this program is to take existing two-cycle components and modify them, where necessary, to

develop a multicylinder engine with a nominal 20 HP engine with growth to 25 HP.

- Engine testing efforts at MERADCOM will emphasize multi-fuel tests, lubrications tests, and noise testing. Efforts will be devoted to evaluation of engines from 15-25 HP R&D program.
- Recovery efforts will center on the evaluation of the study contract initiated in FY76. Advanced recovery systems will be designed, built, and validation tested.
- The RPV configuration optimization studies on the fixed wing will be completed. The study will be expanded to cover rotary wing and VTOL RPV concepts.
- Noise reduction and visual detectability reductions for aircraft of the Aquila configuration will be the major thrust of the survivability program.

PROGRAM PRIORITIES

General. Table RV–B presents, in a prioritized listing, the RPV technology subdisciplines, subsystems, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The RPV technology subdisciplines are as discussed in this section and consist of the following major topical items:

- Air Mobility
- Lasers
- Radar
- Command and Control
- Visionics

Subsystems. Subsystems, as related to RPV technology, are categorized as follows:

- Airframe
- Command and Control
- Ground Control Station
- Mission Payloads
- Ground Support System

System Effectiveness. In the area of system effectiveness, performance is the primary element. Life cycle costs are not ranked in the priority listing since the system must be a low cost item to be effective.

Priorities. With reference to table RV–B, the RPV subdisciplines, subsystems, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

The RPV supporting technology thrusts (as shown in figure RV–2) are five-fold:

TABLE RV–B
PRIORITIZED RPV OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	VEHICLE SUBSYSTEMS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Air Mobility	I	• Airframe	I	• Vehicle Performance	I
• Command & Control	II	• Command & Control	II	• Survivability	II
• Visionics	III	• Ground Control Station	III	• Controllability	III
• Lasers	IV	• Mission Payloads	IV	• Target Acquisition and Designation Capability	IV
• Radar	V	• Ground Support System	V	• Reliability	V

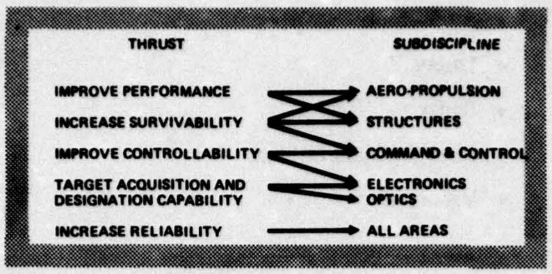


Figure RV–2. RPV program thrusts.

- Improve performance
- Increase survivability
- Improve controllability
- Develop target acquisition/designation capabilities
- Increase mini-RPV reliability

These thrusts are interactive and require expertise from several disciplines as shown. Each of these thrusts are directed toward the development of a capability that does not now exist in mini-RPVs.

LABORATORY PROJECTS IN RPV TECHNOLOGY

INTRODUCTION

RPV technology development effort is directed towards exploratory development (6.2) and was a new start in FY76. The program is particularly responsive to the requirements set forth in AVSCOMs RPV Program Manager.

All developmental efforts are conducted by the AMRDL Eustis Directorate at Ft. Eustis, Virginia by either in-house efforts or by contract. Support is also obtained from MERADCOM, TECOM, and HEL.

DESCRIPTION OF PROJECTS

Remotely Piloted Vehicle Technology. Project 1F262209AH76–TA IX is an exploratory development effort to develop and evaluate new technologies in the aeronautical factors which appear to be limiting the operational potential of RPVs for Army missions. Primary emphasis will be given to the development of engine/propulsion systems, launch and recovery techniques, safety and survivability and the determination of optimum mini-RPV configurations for Army missions. In addition, prelaunch diagnostics, stability and control, and man machine interfaces will be investigated. The general approach will seek to identify potential systems for Army mini-RPV utilization and, wherever feasible, evaluate these systems via wind tunnel or experimental testing.

Remotely Piloted Vehicle-Supporting Technology. Project 1S76273AF34 was established in FY77 to develop and evaluate new technologies in those factors which currently limit the operational potential of RPVs for Army missions. Emphasis will be given to the development of command and control equipment, lasers, radars, visionics, and air mobility capabilities. Day, night, and all weather capabilities will be developed for mini-RPVs for several Army missions. These capabilities do not now exist within the services. Specifically, developments will be pursued in propulsion, launch and recovery, survivability, and manufacturing technology for low cost, mass produced vehicles. Visionics developments include cost/weight reductions on day TV, thermal imagers, and low light level TV. Radar developments will emphasize all weather capabilities; laser programs will develop lighter, more powerful, and higher duty cycle equipments for mini-RPVs. Command and control efforts focus on the development of the Fast Frequency Hop technique as an alternative to the Integrated Communication and Navigation System.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the RPV technology R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 R&D efforts are shown in table RV–C. Included in the table is the ratio of the RPV technology efforts to the total 6.2 AMRDL R&D efforts.

TABLE RV–C
RPV TECHNOLOGY FY77 FUNDING (COMMAND SCHEDULE)

PROGRAM CATEGORY	PROJECT/TECH AREA	AMOUNT (IN THOUSANDS) & PERCENT OF AMRDL FUNDS DEVOTED TO THIS TECHNOLOGY IN FY 77	
6.2*	1F262209AH76-TA IX	485	3%
6.2*	1S76273AF34	1500	9%

*Does not include Project 1F262201DH96 Aircraft Weapons Technology funds.

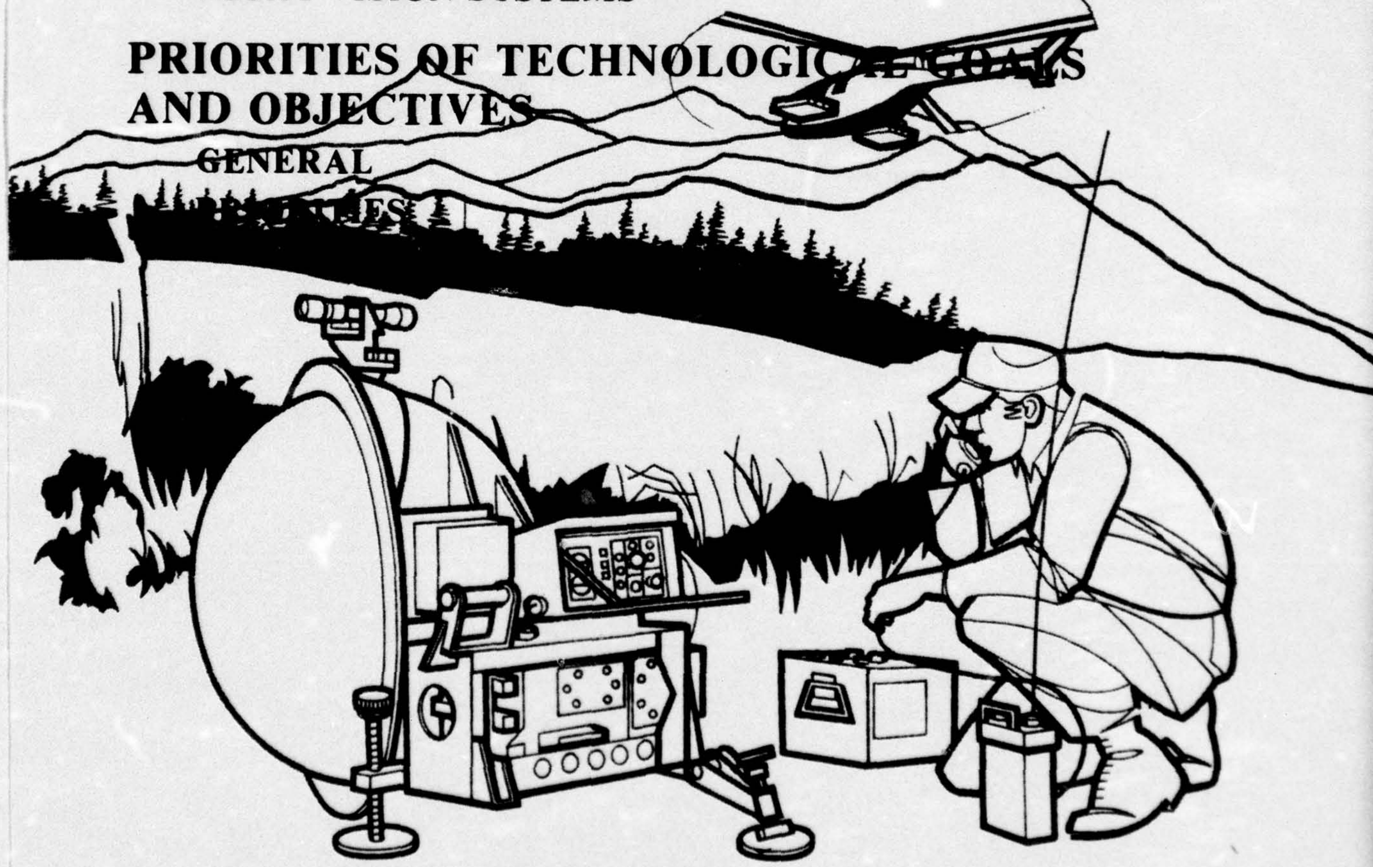
INTRODUCTION

TECHNOLOGICAL DISCUSSION

AVIONICS SYSTEMS
COMMUNICATIONS
NAVIGATION
TACTICAL LANDING
AIR TRAFFIC MANAGEMENT
ENVIRONMENT SENSING
INSTRUMENTATION
SURVEILLANCE AND TARGET ACQUISITION
NIGHT VISION SYSTEMS

PRIORITIES OF TECHNOLOGICAL GOALS AND OBJECTIVES

GENERAL
PRIORITIES



INTRODUCTION

Aviation electronics equipment is that airborne or ground equipment in support of aircraft which relies primarily on electronic implementation. The US Army Electronics Command has been given the overall responsibility for avionics research and development within the Army. The US Army Aviation Systems Command, as Weapon Systems Manager, provides guidance and direction through close coordination between the ECOM Avionics Laboratory, the AVSCOM US Army Airmobility Research and Development Laboratory, and AVSCOM Project Managers. Avionics subsystem/system R&D efforts provide avionics/interface candidate information and equipments for the tradeoff analyses and final system syntheses by the aircraft system designers. Army aircraft in support of ground tactical elements will depend upon improved avionics to provide day/night and adverse weather capabilities for increased survivability and mission capability.

Major increases in future Army aircraft system effectiveness, in a mid-intensity environment, are greatly dependent on increased avionic capabilities. To obtain this greater effectiveness, more avionic functions will be required. There will be a tendency to increase space, weight, and power provisions to accommodate new avionics functions. However, the continuing development of smaller and lighter electronic devices will somewhat offset these increases. If the avionics equipment required for mission performance increases as the functional use of the helicopter is expanded, provisions for weight and space growth must be provided to accommodate the expanded avionics. Although the required avionics functions will provide increased capabilities, e.g., adverse weather low-level operations, the overall increase in the weight and space of avionics will be comparatively small.

Avionics represents an indispensable part of the total aircraft system if full capability is to be achieved; but it also can be a substantial part of the total system cost. In this respect, aircraft of a generic type having multiple mission roles are to be equipped with provisions for the various avionics systems, but the equipment will be selectively installed according to the particular aircraft's mission assignment. This concept must be evaluated for each particular aircraft with respect to maintenance and weight burden. Also, since aircraft usually remain in the Army inventory for extended periods (20 years or more) second-generation avionic configurations become logical candidates for future retrofit programs for in-service aircraft.

The near-term avionics R&D objectives, the major thrusts they support, and the current projects to meet the objectives are shown in figure AV–1 (located at the end of this section). Full use of airmobile systems is directly affected by technological advances in these avionic activities. The accomplishment of unique mission capabilities, such as those associated with night operations and weapon detection and location, are examples of near-term R&D goals. Helicopter operations require avionics systems with integrated instrumentation and sensors to accomplish specific tasks. No longer will typical fixed-wing avionics be altogether acceptable for helicopters. Low-level, night operational requirements will require further delineation, and corresponding development efforts in the areas of obstacle detection and avoidance, pilot night vision systems, precision hover, low-level navigation, non-line-of-sight communications, stability augmentation, integrated instrumentation/displays, and ECM (passive and active). The avionics package, along with the other major subsystems (airframe, propulsion, and weapons), must be adaptable to both single and multiple mission requirements. Life cycle costs, reliability, availability, and maintainability system tradeoffs are of primary importance in the selection of final aircraft system designs.

The aviation electronics portion of the long-range plan is divided into ten functional areas:

- Avionics Systems
- Communications
- Navigation
- Tactical Landing
- Air Traffic Management
- Environment Sensing
- Instrumentation
- Surveillance and Target Acquisition
- Night Vision

Each will be discussed individually, with specific attention paid to current and future programs.

TECHNOLOGICAL DISCUSSION

AVIONICS SYSTEMS

GENERAL

An advanced avionic systems program is required to interface avionics technology development efforts with the operational requirements of Army aircraft. The main thrust of this program is an early flight test validation and evaluation of the effectiveness of various avionic equipment sets – the "fly before require" concept. This pragmatic approach to systems engineering is comprised of an iterative, three-step process of analysis, simulation, and flight test. The results of this process form the basis for the development of avionics system level specifications for Army aircraft developmental and product improvement programs. Another use of this technique is for the identification of required advances in specific areas of technology (e.g., navigation and environment sensing) that should be further investigated by the proper research organizations. To accomplish the above, the following types of effort and capability are mandatory:

Analysis. The initial analytic effort involves the translation of specific mission requirements into candidate avionics hardware configurations with special emphasis on identification of the subsystem characteristics (accuracy, range, power, etc.) and system characteristics (EW vulnerability, EMI compatibility, and equipment interfaces) necessary to fulfill the specific mission requirements. These efforts also serve to identify those problems that are not amenable to solution by analytic methods, which then become potential candidates for simulation and flight test. After candidate hardware configurations have been proposed, the application of advanced system integration techniques (digital/modular integration, light interface technology, data bus, multiplex, etc.) is considered for each hardware integration program. The most restrictive barrier to the success of this effort is the acquisition of a well-coordinated, generally accepted description of the mission to be accomplished, without prejudgment as to what equipment is necessary to execute the mission. This barrier must be addressed through close, continuing coordination between the using and developing communities.

Simulation. The objective of this effort is to develop hardware integration concepts for avionics configurations that have been identified under the analysis effort as candidates for further development, and to forward the most promising concepts to flight test for validation of the hardware integration plan. This objective is achieved by utilizing the simulation facility as an evaluation tool in a five-step approach:

- The simulation test activity is used for a relative evaluation of avionic system configurations developed under the analysis effort.
- For those configurations with satisfactory simulation results, a bench test facility in the simulator is used to demonstrate the feasibility of the hardware integration technique.
- Computational requirements are identified for integration of the candidate configurations.
- The simulation facility is used as a preflight training aid in the preparation and evaluation of a flight-test plan.
- The facility is used as an avionic system design tool for those cases that cannot be handled by the analytic approach previously described.

There are two major barriers in the simulation area. The first barrier is the digital computer execution time of a complete model of a single rotor helicopter consisting of the six aircraft fuselage degrees of freedom, the rotor rotational degree of freedom for autorotation, and algebraic expressions for the rotor first modal coning and flapping. As this model usually requires 30 milliseconds to execute (out of a permissible 50 milliseconds), very little computation time remains to simulate avionic-related functions. This problem is being attacked by the development of a special purpose analog helicopter simulator. The second barrier is the difficulty in correlating the information content of a video display for the pilot (presently accomplished with a TV/moving belt system) with the information content from simulated sensors such as a CO_2 terrain-scanning laser. This is being addressed by acquisition of a digital land-mass simulator which will have the potential for generating the video information and the avionic sensor information from a common data base.

Flight Test. The objective of this effort is to provide an airborne test activity for validation of avionics hardware configurations. This objective is achieved in four ways:

- An instrumented test bed aircraft (CH-53A) is used to prove the performance capability of

avionics systems and to validate the hardware integration concepts identified by analysis and simulation.

- The instrumented aircraft is used as an avionic systems design tool for those problems that were not amenable to analysis or simulation.
- In those cases where a user element or test activity (CDEC, MASSTER, TECOM, etc.) requires an avionics system integrated into a particular operational aircraft, a prototyping activity is used to install and validate the performance of the avionics equipment prior to delivery of the aircraft to the appropriate activity.
- All data and experiences gained in the analytic, simulation, and flight test phases of the test program are utilized to produce system level specifications for the avionic configurations.

There are two barrier problems associated with this flight test activity. The first problem area is somewhat philosophical, as it concerns the general acceptance of test-bed flight test results. It is considered reasonable for a simulation/flight test activity focusing on avionics problems to provide a valid data base for avionics equipment development without the human factors, aircraft stability and control, aeromedical, and other considerations having been optimized. The requirement in these associated disciplines is that their influence be reasonably considered. To insure the reasonable treatment of these influences on avionics equipment development requires close coordination and cooperation between the appropriate agencies. The second problem relates to the flexibility required in a test-bed type of a flight program – which is somewhat difficult to achieve. It is mandatory from cost considerations that the ability to rapidly reconfigure the test aircraft be developed. This ability permits execution of overlapping or even simultaneous flight test programs and allows for a quick reaction systems test capability.

In accordance with DARCOM major thrusts toward improvement in survivability and night operation, this three-step methodology is being applied to the synthesis of avionics systems suitable for tactical Army operation in the low-level (for survivability) night environment.

NIGHT NAVIGATION/PILOTAGE SYSTEM

One of the more difficult avionics system problems for operation in this environment is the navigation/pilotage problem. The need for operating low level at night gives rise to several unique problems, such as:

- Experience at CDEC and elsewhere indicates that maintaining proficiency for flying low level with the unaided eye requires high motivation and continuous practice.
- Safety of flight problems arise because the observer is night blind when using mission equipment such as a target acquisition system and if the other operator gets in difficulty, the observer cannot take over control of the aircraft in the time available to do so.

Solution of these problems requires development of a general purpose display compatible with night vision aids such as the AN/PVS-5 night vision goggles. Such a display would have growth potential for the display of mission equipment data, diagnositcs, etc. Our near term thrust, however, will focus on display of the information needed for navigation/pilotage.

The approach being taken is the injection of imagery and other high resolution information into the AN/PVS-5 goggles by means of a fiber optic rope. For day use, the fiber optic rope is terminated in a silvered prism mounted on the pilot's helmet. This concept is called MAD, for *M*ultifunction *A*viation *D*isplay. It may be thought of as a Helmet Mounted Display (HMD) within the goggles, wherein the information, focused at infinity, can be displayed in one eyepiece of the goggle available as a backup in case of sensor failure, aircrew casualties, etc. A preliminary model of this device has been fabricated and simulator tests have been initiated to assess the basic utility of the concept. If development of the MAD can be pursued to the point where its operational use can be feasible it would have significant beneficial impact on Army cockpit design. The primary barrier to this (which is not addressed in the preliminary model) is achieving compatibility of the total weight on the pilot's head with aeromedical considerations. Overcoming this barrier will require intensive closely coordinated effort by all involved agencies.

Other efforts required for synthesis of a navigation/pilotage system address the problem of getting the required data to the display, that is, map information and symbology. Digital generation of flight symbology (attitude lines, etc.) in a TV compatible raster scan format has been accomplished. The next step to be undertaken is digital generation of alphanumeric data. The basic problem being addressed in

digital map generation is to include information required, avoid clutter of information not required and keep complexity, and hence cost, low enough for application to Army aircraft. Efforts are underway to carry out relative assessment of differing formats such as ridge-valley line versus contour, various shades of gray, and levels of resolution.

The system elements described above will be integrated with the AN/ASN-128 doppler navigator for system level simulator and flight test assessment.

TACTICAL HOVER

Tests conducted by several Army agencies have demonstrated the extreme difficulty of performing the tactical bob-up hover, bob-down maneuver in manually controlled Army aircraft. From previous work on other applications, a symbology set has been evolved which does permit accomplishment of this maneuver if the sensors driving the symbology are "good enough."

The basic source data involved are heading error, attitude, ground referenced velocity, and ground referenced position. The control problem has two basic parts:

- Stabilizing the aircraft (perhaps with a slow drift over the ground)
- Positioning the aircraft with respect to a desired point on the ground.

Attitude and velocity data primarily bear on the first problem and position data on the second. However, these effects are not uncoupled, that is, excellent position information reduces velocity accuracy requirements and vice versa.

Heading and attitude data from the conventional aircraft equipments are adequate for the task. Further development will thus address tradeoffs among potential sources of position and velocity information. In line with the general philosophy of using avionics subsystems in multifunction roles whenever possible, to reduce system cost and weight, use of the AN/ASN-128 Doppler navigator to supply the required velocity will be investigated, with an "out the canopy" visual input for position. (This implies a "headup" symbology presentation.) If this proves adequate, the Night Navigation/Pilotage System would also afford the capability of tactical hover with the addition of only the required symbology with no new sensors or subsystems. Configurations involving other methods of deriving position information will be investigated as needed, but the emphasis will be on providing the capability with minimum impact on aircraft system configuration.

DIGITAL MODULAR SYSTEM INTEGRATION

The application of digital modular system integration techniques to Army avionic systems will significantly simplify the aviator's workload. In addition, capabilities such as frequency pre-sets for all radios will be added. Of more importances, digital modular system integration techniques have potential for significantly lowering the life cycle costs of avionic systems. These savings will primarily emerge due to the ease with which subsystems can be added or deleted and the ease of maintenance.

In order to exploit this new technology area, two efforts have been undertaken to apply the latest advances in solid state electronic microprocessors and displays to the design of standard integrated avionics panels and aircraft multiplexing systems.

The first is an engineering development effort called the Integrated Avionics Control System (IACS). The program goal is to apply currently available technology to a system integration scheme which will provide the Army with a digital modular avionic system in the near time frame (early 1980s).

The second effort is a long range exploratory development effort called the Digital Modular Avionics Program (DIMAP). This effort is geared to the post 1985 time period. This exploratory effort has provided the technology base for the IACS program and will provide the technology base for future efforts in digital modular system integration.

The Integrated Avionics Control System will provide a single integrated control panel with multiplex control for a number of avionic equipment, including the following:

- VHF–FM radio (2 each)
- VHF–AM radio
- UHF–AM radio
- ADF Receiver
- IFF Transponder
- Communication security equipment

Growth capability for CONUS navigation and NOE communication equipment will be provided. First application of this system is intended for the Advanced Attack Helicopter. Benefits resulting from application of IACS to the AAH include a savings of cockpit panel space, simplified crew operations, and a flexible growth capability that will permit addition and/or deletion of equipment without costly aircraft rewiring.

In addition to the AAH, this multiplex system will have application to all Army aircraft, both standard and developmental, particularly the ASH, CH-47, Cobra, and OH-58.

A simplified block diagram of the IACS is shown in figure AV–2. The system will be designed to allow a number of possible configurations so as to accommodate both tandem and side-by-side cockpits. The primary control panel will allow the operator to interface with all of the controlled subsystems. An optional status panel which could be remotely located at the top of the instrument panel directly under the glare shield will also be developed. A secondary control panel which will have reduced capability will be available for tandem aircraft where room does not permit installation of a primary panel for each crew member. The secondary panel will have the capability of controlling one of the FM and VHF radios and the ADF as a minimum.

The engineering development approach for this effort consists of two parallel competitive contractor efforts using the design to unit production cost concept. Supporting efforts for an improved intercom

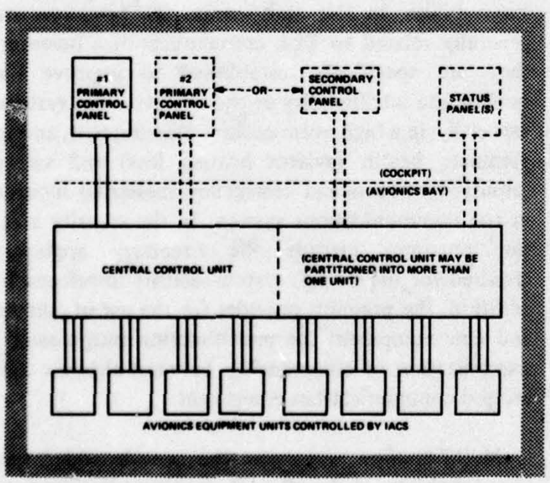


Figure AV–2. Digital/modular avionics core system.

(with selective volume control for each channel) and modified radios will result in a completely integrated avionics package ready for operational tests in FY-78.

The Digital Modular Avionics Program (DIMAP) is the supporting technology base effort in the area of digital modular system integration. This technology base program is closely tied to the Air Force and Navy efforts in this area, especially in digital data bus techniques.

During the past year, all three services agreed on a military standard which calls out the parameters of an aircraft command/response data bus and establishes standard digital interfaces for all avionic subsystems. Using the data bus hardware being developed by these other services, a breadboard system is being fabricated under DIMAP. This system is representative of the post IACS type system in that full data bus techniques will be used. Equipment currently being designed for the IACS will be compatible with the full data bus concept.

The next step in the evolution of multiplex systems will result in a optoelectronic data bus (i.e., a data bus using light interface technology). A small effort is underway under the DIMAP to test the feasibility of converting an exploratory twisted pair data bus to an optoelectronic bus. This effort is being conducted jointly with the Naval Air Development Center.

MULTIFUNCTION USE OF SENSORS

The long-range avionics systems program must emphasize the use of sensors in multifunction roles in order to reduce the cost and weight of the overall system. Two such efforts are currently being undertaken, in addition to the doppler/hover system integration described previously.

- Navigation/Target Acquisition System Integration – One method for determining the UTM coordinates of an unknown target is to use a laser range finder to measure range and angles to the target, combine this data with the UTM coordinates of the aircraft (supplied by the navigation system) and compute the target coordinates. If the coordinates of the target being ranged on are previously known, the same procedure can be followed to compute the UTM coordinates of the aircraft and, thus, "update" the aircraft navigation system. Data on the accuracy with which this can be accomplished will be gathered. Potentially, at least, a

self-contained navigation system could be "calibrated" by ranging on a known checkpoint when nearing the operational area of interest. The navigation system could then provide much better accuracy than would otherwise be possible.

- Wire Detection Laser – A scanning CO_2 laser, Laser Obstacle Terrain Avoidance Warning System (LOTAWS) is under development as a wire detection device. The use of this sensor to provide the data necessary for the generation of terrain-following command information is being investigated.

AVIONICS SYSTEM ASSESSMENT

Realistic assessment of the relative merit of different avionics systems is a continuing and difficult problem. The interrelated areas of pilot workload, pilot opinion, and task performance precision all play a part, especially when aviation displays are being evaluated. When attempting to discriminate among several comparable displays, one typically finds the task performance precision data to be inconclusive "flat data." With the poorer system(s), the pilot simply works harder to achieve the same tracking error performance. Reliable techniques for accurate, repeatable assessment of the pilot's workload are, therefore, needed to provide the necessary discrimination. Such techniques are not presently available for use in flight test. A promising technique suitable for use in ground-based simulation tests is being developed. Basically, it involves keeping the pilot working at his maximum capacity through manipulation of a single parameter, with the differing value of the parameter in tests of different systems serving as the discriminator. In order to address the flight test problem, attempts are being made to correlate variation in the physiological state of the pilot (heart beat, etc.) which can be measured in flight, with variations in this parameter during simulator experiments. Preliminary results are encouraging.

EW VULNERABILITY/ECCM ASSESSMENT

Hostile electronic warfare activities present a serious threat to our ability to conduct military operations. Unless the seriousness of this threat is acknowledged and countered, it can degrade the ability of the military to shoot, move, and communicate, hence field weapons systems would not be effective against a sophisticated enemy. In recognition of the seriousness of this problem, the Army Material Command issued the EW policy letter of 2 January 1974 that requires electronic counter-countermeasures to be considered in every DARCOM weapons systems development. As part of the implementation of this policy, EW vulnerability assessments are being conducted on the AAH and UTTAS. An EW vulnerability assessment for the ASH will be initiated in the near future. The objective of these assessments is to (1) evaluate the ability of specific weapons systems to function in an EW environment, (2) formulate ECCM requirements and (3) recommend corrective actions. The ultimate goal of these assessments is to improve the ability of Army aircraft to function and survive in a hostile EW environment.

COMMUNICATIONS

GENERAL

The goals of the airborne communications program are divided into three major thrust areas:

- Tactical Low-Level (TLL) Communications
- Audio Processing, Distribution, and Isolation
- Secure/Jam Proof Communications

TLL communications encompasses the requirement for communications while aircraft are flying nap-of-the-earth profiles. The primary objective is to increase mission effectiveness by providing a system which will maintain a reliable and secure communications link so that aircraft can fly at low levels for survivability. In the audio area, the programs are generally related to TLL communications; however, they are specifically established to improve the quality and intelligibility of the aircraft audio system, especially in a high-noise cockpit environment, and to eliminate health (aviator hearing loss) and safety (ability to understand emergency messages) hazards in the communications system. In the security area, the programs provide the necessary appliques required for the aircraft system security interfaces. In addition, the program provides for the use of current and new equipment for multifunction purposes and maximization of commonality between airborne and ground communications equipment.

Multifunction equipment can provide added system capability at lower cost, resulting in increased mission effectiveness. Specific areas include the use of

a phase detection technique to provide a universal FM radio phase front homing system. The same concept will be used to develop low cost VHF/FM hover and range/bearing (ADF) sensors, using the standard aircraft FM radio. Tri-service support and coordination will continue for the development of search and rescue equipment. Support will be provided to the Digital Modular Avionics Program as regards communications equipment and interface requirements.

TACTICAL LOW-LEVEL COMMUNICATIONS

Future aircraft missions and roles will force demands on the ability to communicate effectively at low altitudes with a high degree of reliability and flexibility. To support future airmobile systems, major advances in the multiple use of radio sets for tactical communications, with added operational functions such as data transmissions and automatic direction finding (ADF), will be required. Additional features will include added channels, preset channels, and rapid remote tuning from a compact simplified control panel, X-mode compatibility, noise-abating audio transducers, and transmit-on-emergency frequencies. New generation radios will be ultrareliable, compact, and multifunctional, with reduced vulnerability to enemy interference. This second-generation Aviation Communication Equipment could be available to support operations in the 1980-1990 time period. Battlefield commanders will have airborne communications/retransmission consoles to maximize on-the-spot control of tactical situations and ensure timely decisions affecting tactical operations.

The current family of Standard Lightweight Avionics Equipment (SLAE) radios (AN/ARC-114, 115, 116, and 164) have made state-of-the-art weight and space reductions of approximately 30 to 7 lb and 1,700 to 190 in.^{3}, respectively. The new AN/ARC-98 HF/SSB airborne radio provides a 30 percent size-and-weight reduction over its predecessor. Mean time between failure of this new equipment is currently on the order of 1,000 hr. This advancement came about largely because of miniaturization of electronic components, including transistors, microelectronics, along with printed circuit techniques and novel circuit design approaches permitting breakthroughs in size and weight factors.

Objectives for the 1980-1995 timeframe include fielding of next generation communications equipment with MTBFs on the order of 3,000 to 5,000 hr, further reduction in size and weight, multiple preset channel capability, simplified control and adaptability to remote tuning, and 25-KHz channel spacing. The use of advances in integrated circuit technology will make the aforementioned advances possible, along with inclusion of diagnostic and testing circuitry for built-in automatic testing of communications equipment down to individual module level. Audio transducers and interphone system redesign will reduce the possibility of aviator hearing loss due to excessive aircraft system noise levels. Automatic direction finding techniques will be extended to the FM band for search and rescue operations. Continued emphasis on standardization and commonality will facilitate quick disconnect interchangeability and maintenance replacement of radio gear in all Army aircraft. Incorporation of SLAE radios into a command console and a retransmission system will result in small lightweight systems for use in Army tactical helicopters. Later versions planned for development will utilize digital transmission capabilities. Additional development goals include low-drag antennas with dependable pattern coverage for aircraft.

Long-term approaches to provide multiple channel, reliable, and secure communications, anywhere on the battlefield, include:

- Small RF repeaters, which can be installed in any applicable vehicle/ground station (e.g., aircraft, satellite, balloon, RPV, tower, etc.) and may also be used as standard transceiver.
- Time Digital Multiple Access (TDMA) or Integrated Communication, Navigation, Identification (ICNI) systems (e.g., PLRS, SEEKBUS, ITNS) which are being investigated by USAF, USN, and Army, for ground and airborne use.
- Advanced communication and antenna techniques must also be developed to permit reliable communications in an EW environment.

The Tactical Low Level communications development plan includes:

- The study and development of improved antenna techniques, such as:
- Dual-frequency antennas (allows two radios operating in the same band to use one radiator).
- More efficient flush mounted antennas and antenna couplers to obtain more effective radiated power from the aircraft.

- Aircraft model antenna pattern measurements to determine best location and optimum configuration.
- Test, analyses and evaluation of:
  - High power radio amplifiers
  - Satellite communications equipment
  - Single side band operation expanded to 80 MHz
  - Single frequency ($F_1 - F_1$) retransmission (provides extended range and more effective utilization of the frequency spectrum for combat operations).
- Smaller HF/SSB equipment for use in space and weight limited aircraft and small VHF/FM command and control/retransmission consoles.

AUDIO PROCESSING, DISTRIBUTION, AND ISOLATION

The audio development effort encompasses improved microphones with better noise cancelling features and flatter frequency response characteristics; noise reduction headsets which will lower the outside noise that reaches the aviator's ear and, thus, reduce the high incidence of aviator hearing loss; and whine and electronic noise cancelling devices to reduce the total audio system susceptibility to outside acoustic noise interference. Improvements in the aircraft intercommunication radio equipment for better quality and intelligibility under combat conditions will permit non-routine messages to be clearly understood with first-time reliability. Improved audio signal processing (such as automatic gain control, signal compression, etc.) will also be investigated. These efforts include a complete analysis of all audio signals, and sources, and the establishment, in conjunction with USAARL, of a set of audio standards (e.g., levels, distortion, intelligibility, etc.) for all airborne communications that will minimize health (aviator hearing loss) and safety of flight (intelligibility) hazards.

SECURE/JAM PROOF COMMUNICATIONS

The Secure Communications (COMSEC) development effort encompasses new techniques and devices to increase circuit isolation in the aircraft system that the secure messages cannot be inadvertently transmitted on non-secure links. A universal voice gate circuit adapter, for use in all aircraft as an aircraft security interface device, and other such devices, will be developed, to assure proper integration of COMSEC into all aircraft.

The Electronic Counter-Countermeasures (ECCM) program for airborne communications can be divided into three areas:

- Steerable null antenna processor for airborne communications (SNAPAC).
- Application of Fast Frequency Hopping (FFH) to airborne communications.
- EW vulnerability assessment of nap-of-the-earth communications.

The SNAPAC involves investigating steerable null antenna processor technology for application to airborne communications. Primary emphasis is on techniques that could be utilized with existing narrow band radio sets. Technical barriers include rotor blade modulation, tracking speed, and signal acquisition/identification. A steerable null processor (intended for ground applications) has been installed in a UH–1 and static ground tests completed with the rotor blades rotating. Limited flight tests have also been conducted. Problems experienced during the flight tests have delayed testing until an improved processor can be evaluated. If subsequent flight tests provide encouraging results, feasibility models of a steerable null antenna processor will be procured.

Fast Frequency Hopping is being developed for high protection ECCM of priority net links in the Single Channel Ground and Airborne Radio System (SINCGARS). Application of FFH technology to airborne communications will be investigated in FY-77.

Efforts will be initiated to evaluate the ability of nap-of-the-earth communications to operate in an EW environment. Various interim approaches will be evaluated in addition to looking at long term solutions. ECCM requirements will then be formulated.

NAVIGATION

GENERAL

The Army's airmobility mission has generated a need for aircraft to establish their position wherever they might be employed; to determine velocity, attitude, and heading for fire support, surveillance, and intelligence missions; and to navigate reliably and

accurately under adverse, day-to-night, near all-weather conditions. Navigation systems may be divided into three general types: self-contained, externally referenced, and hybrid. The Army has the following navigation systems in the inventory:

- Self-contained – AN/ASN–86 inertial system: AN/ASN–64 with AN/ASN–76 Doppler-heading reference, and AN/ASN–43 heading reference (used by the pilot in conjunction with the airspeed indicators).
- Externally referenced – AN/ARN–89: AN/ARN–82A VOR and AN/ARN–103 TACAN.
- Hybrid – AN/ASN–86 with AN/ARN–103: TACAN inertial.

These systems, unfortunately, suffer from various shortcomings. The present self-contained systems are too heavy, cost too much, and have low reliability (AN/ASN–86 and AN/ASN–64 with airspeed update). Externally referenced systems now used are subject to interference from enemy and weather (ADF), in some cases are restricted to line-of-sight (TACAN), and are not accurate for position location (ADF or VOR). The present hybrid system is heavy and has a high cost and low reliability. Other systems currently available, but not in use by the Army, include the latest generation of inertial and Doppler systems (lower cost, lighter weight, and potentially higher reliability), LORAN receivers (high accuracy, externally referenced, not restrained to line-of-sight), OMEGA (worldwide, externally referenced, medium accuracy), DME (line-of-sight, short range, externally referenced, extremely high accuracy) and various hybrid systems combining the advantages of both self-contained and externally referenced systems (LORAN/inertial, LORAN/Doppler, inertial/DME, etc.).

With the Army's aircraft environment, the R&D objectives for self-contained systems are to lower the cost (from $100-$250 K to $25-$75 K) and weight (from over 100 to 25-50 lb) while increasing the reliability (MTBF less than 300 to 500-1,000 hr) and achieving an accuracy of 2 percent or less of the distance traveled. Research and development on externally referenced systems has as its objectives, by the use of low frequency radio navigation such as LORAN, the reduction of cost (from $100 to $20 K) and weight (approximately 30 lb), higher reliability (500-1,000 hr MTBF), establishment of a worldwide capability, and development of a system as secure as is possible.

The objective of R&D on hybrid navigation systems is to provide superior performance/invulnerability with minimal increase in cost and weight. Thus, one objective is to develop systems having a greater capability than any single sensor for those missions with the most stringent requirements. Hybrid systems will also offer backup modes not available with single sensor systems, affording such advantages as the ability to operate effectively in spite of interference (intentional or unintentional) with externally referenced systems such as LORAN, Global Positioning System (GPS) satellite navigation, or Time Division Multiple Access positioning networks. Finally, via the hybrid technique, the high-position-accuracy, external reference system can calibrate the self-contained system in flight via Kalman Filtering. This updates self-contained system accuracy, and if the external reference system is jammed, etc., the self-contained system would continue with a higher order of accuracy.

An example of this latter type of positioning network, which is being actively pursued by the Army via joint USMC/USA development, is the Position Location Reporting System (PLRS). PLRS is a TDMA system that operates in the UHF band and is capable of providing the integrated functions of navigation, identification, and communication. It utilizes spread-spectrum and encryption to provide optimum EW protection, and employs automatic surface or aerial relays to achieve over-the-horizon capability between the master (net management/data processing) unit and the user receiver/reporting units (manpack or vehicle mounted).

SELF-CONTAINED SYSTEMS

A new inertial navigation system to meet the Army's needs must be developed using the current state-of-the-art. The feasibility of new approaches to inertial navigation, such as strapdown, which promises to lower the cost and increase the reliability, must be investigated. Ongoing, self-contained systems programs have planned IOC dates in the 1980s. Prime candidates are systems in development for other services such as the Navy laser gyro and the USAF MICRON systems. Updated Doppler technology must be used as a follow-on to the present engineering development program for further cost reduction in

this area. Another candidate being investigated is radiometric ground velocity sensing which offers the potential of high accuracy with low cost and weight in a passive, nonemitting technique, for increasing inertial and other navigation system performance. The development of a low-cost heading reference is underway, first, to improve the ASN-43 by compensating its errors in the Doppler Nav computer, and second, to flight test other promising low-cost heading reference.

EXTERNALLY REFERENCED SYSTEMS

Following the current airborne LORAN engineering development with FY-79 IOC, the next generation of low-frequency radio navigation should consider direct ranging with increased accuracy, reliability, decreased unit cost, and improved ECCM techniques. Although cost is a prime factor, satellite navigation receivers, adapted to the Army environment and compatible with other GPS developments, also must be investigated. The second phase of development of the PLRS should be undertaken to complement GPS as well as to determine its full capability to meet future requirements at a cost the Army can afford.

HYBRID SYSTEMS

The development of GPS and PLRS sensor models and optimal and suboptimal combining algorithms for GPS and PLRS Doppler and Inertial Hybrids must be continued, including hardware verification and flight tests. Also, new inertial and velocity sensors must continue to be investigated for their application to hybrid systems (such as ring laser gyros, and microwave radiometric velocity detectors, and nuclear magnetic resonance systems). The near-term goal is synthesis of a LORAN/Doppler system. Joint service testing is also underway on hybrid Doppler and air data navigation systems with TDMA positioning networks. Results of this effort are in the process of publication.

SECURE NAVIGATION

The LORAN–D ECCM coding program will continue to be supported by the Army and Air Force. Various coding techniques are being investigated for the purpose of selecting an optimal coding technique for existing LORAN–D receiver designs. Phase I of the Joint Army/Air Force investigation and evaluation of various pseudo-random (P/R) codes has resulted in the selection of the most technically suitable and cost effective P/R code. During Phase II of this program, the Army will modify the AN/PSN-6 LORAN manpack receiver and the Air Force will modify the AN/ARN-101 airborne receiver to incorporate the P/R code selected in Phase I. The modified receivers will be subjected to simulator tests to validate the ECCM capability and receiver performance. Subject to the availability of funds, field tests will be conducted during FY-7T on the AN/PSN-6 and the AN/ARN-101 receivers to determine the P/R code performance against a transmitter jammer. Initial planning and preliminary theoretical work is also underway to support EW vulnerability testing of the Army's airborne LORAN–D receiver (AN/ARN-114). Tests were completed in FY-76. ECCM requirements have been established for doppler navigators based on preliminary EW vulnerability estimates. Field tests were conducted in FY-76 to verify key aspects of the theoretical assessment. An EW vulnerability assessment of airborne receivers for the Global Positioning System was initiated in FY-76. An investigation to optimize hybrid navigation systems in an EW environment was also initiated in FY-76.

PRODUCT IMPROVEMENTS

Although no R&D is involved, various degrees of VOR, ILS, and DME capabilities are being incorporated into many in-service aircraft (e.g., UH–1 and OH–58). This civil airway navigation capability will meet the new FAA split channel requirements. New small, lightweight, reliable, and inexpensive commercial-type equipment is being procured for this purpose.

TACTICAL LANDING

GENERAL

Tactical landing refers to Army aircraft conducting landing approaches to very low heights or to full touchdown landings under nonvisual tactical conditions. Since man's first attempts at nonvisual approach and landing, the primary technique has been to establish a reference descent path in space through radio signals from ground equipment. In the case of GCA (Ground Controlled Approach), the ground equipment is a radar set, and ground-derived aircraft position data are used to steer the pilot by voice or data link. In the case of ILS (Instrument Landing System), the ground equipment radiates beams that, in themselves, form reference descent

path signals in space. In ILS, a cooperative airborne receiver converts these ground-radiated signals to steering information that is displayed to the pilot on cockpit instrumentation. In both GCA and ILS, the aircraft is constrained to fly a specific path to a specific point, the safe location of the descent path having been carefully predetermined by ground personnel. The ultimate tactical landing capability is seen as deriving from a technique in which all equipment is self-contained onboard the aircraft, and no assistance is required from ground personnel or equipment.

After nearly 50 years of landing systems development, the state-of-the-art now provides nonvisual landings to decision heights of 200 ft and Runway Visual Range (RVR) of 2,400 ft (the civil category I landing) with both GCA standard VHF/UHF ILS under the "see to land" concept (i.e., visual aids and lighting are provided to aid the pilot in executing a visual landing after a nonvisual approach to a point 200 ft above the landing site). While several standard ILS-equipped airfields and some aircraft have been certified for category II landings (a decision height of 100 ft and a RVR of 1,600 ft), category II landings are presently not an operational reality for Army helicopters. Several microwave ILS techniques, evolved over the past decade, are vastly superior to standard VHF/UHF ILS because their spatial beams are formed completely by antenna apertures of reasonable dimensions and do not depend on favorable ground reflection to develop flyable signals in space. The FAA has selected a 5-GHz Interim Microwave Landing System (IMLS) to provide landing guidance at those sites where terrain conditions prohibit the installation of conventional VHF/UHF ILS. Decision heights of the IMLS will typically be category I. Also, the Navy authorized a 200-ft decision height aboard aircraft carriers with a 15-GHz scanning beam system very similar to that being developed under the Army TLS (Tactical Landing System) program. Technical barriers to realizing an Army tactical landing capability with an ILS involve establishing safe landing guidance in adverse terrain and solving the instrument-to-visual transition problem peculiar to the steep approach angles of the helicopter and austere landing sites. With regard to the self-contained landing capability, several image-forming sensor techniques (radar and infrared) have been investigated. While a degree of capability has been demonstrated, no technique accomplishes all of the functions required of a self-contained landing system, that is, locate and positively identify the landing point with no assistance from the ground, establish an obstacle-free descent path, provide guidance information with which the pilot can execute the descent to or below visibility minimums existing at the site, and indicate any system malfunction that would jeopardize acceptable completion of the landing.

TACTICAL LANDING OBJECTIVES

The Primary R&D objectives in tactical landing are:

- To generate usable microwave guidance to well below the category II decision height of 100 ft for the full range of descent angles negotiable by fixed-wing and rotary-wing aircraft in adverse landing sites.
- To ensure maximum system immunity to degrading multipath effects and generate guidelines for system operational deployment.
- To determine minimum night/IFR, visual-aid/lighting requirements for the breakout-to-touchdown segment of the landing.
- To examine decelerated approach breakout transition problems for effective use of guidance below the 100-ft decision height.
- To ensure that Army needs are incorporated into the National Microwave Landing System (NMLS) under development, since the national program will adopt a new common civil/military signals-in-space standard (replacing the standard ILS), possibly by the end of FY77.

New capabilities to be investigated include the use of advanced cockpit displays and control systems for decelerating approaches along straight-line and curved-descent paths, high-density landings with aircraft separations of but a few thousand feet, and automatic landings. No current effort is underway specifically addressed to solving the self-contained landing system problem. The intent is to concentrate on realizing an actual IFR capability with the cooperative microwave TLS and then to apply that experience in a search for promising approaches to the self-contained problem.

TACTICAL LANDING PROGRAM

The present TLS development provided ground, airborne, and test equipment for developmental and operational testing in the first quarter of FY75. Equipment for the UTTAS prototype aircraft was

provided in the same timeframe. DT II/OT II testing of the TLS was completed in the 2nd quarter of FY-76. TLS equipment was provided to the 101st Airborne Division at Ft. Campbell for evaluation. The evaluation was initiated and is scheduled for a 12 month period. The DEVA IPR is scheduled for the 3rd quarter of FY-76. The type certification (LP) is scheduled for March 1976 with an IOC date of September 1978. The UTTAS prototype aircraft which are equipped with TLS have been undergoing contractor flight tests during FY-76.

The National Microwave Landing System Program is a joint DOD, DOT, and NASA effort, with the FAA as the lead agency. In December 1974, a technical evaluation team recommended a provisional system technique/signal format for adoption as the US standard. This format will be tested by each of the user agencies using hardware to be developed in the following phase of the program. Final ratification and evaluation will start in FY78. Under the NMLS program, investigations will be completed into propagation effects, steep approach displays, coupled helicopter approaches, and special component developments. The FAA is expected to enter a Contract Definition program for Military MLS equipment in FY7T. This will lead into an engineering development program, possibly as early as FY77. During FY76, internal flight research efforts in support of the MLS have demonstrated the potential for performing both manual and fully automatic steep angle, decelerated, helicopter approaches to a hover using relatively unsophisticated airborne flight director displays, automatic flight control systems and flight path couplers. In FY77, this effort will be extended to conduct actual IFR flights to examine the full operational implications of low visibility tactical landing approaches, for example, tactical lighting, instrument to visual transition problems and avionics system redundancy/integrity aspects. Additionally, the ability of candidate MLS equipment to provide high-integrity guidance in a high-density helicopter landing environment is being explored through the use of an integrated MLS and Air Traffic Control Display System (termed the crossbanded system). Also, the potential of the crossbanded system to serve as a transportable, terminal ATC facility will be investigated. This work will support both the TLS and NMLS efforts. The first investigations into the self-contained landing system problems are scheduled to start in FY77.

The Army will use the TLS and NMLS programs to establish a sound basis for generating a fleetwide tactical instrument landing capability. To date, results indicate that TLS will serve all Army aircraft with sufficient guidance to instill pilot confidence quickly. While initial operational capability will probably be set at a 200-ft decision height, the guidance provided by TLS (unlike standard ILS) will be usable well below a decision height of 100 ft, so that increased operational capability will derive from evolutionary improvements in displays, piloting skills, visual aids, etc. The NMLS program promises a mechanism for achieving fully compatible operation among the military services (and civil aviation as well). Because of the basic similarities between the TLS and NMLS concepts, Army experience and capability derived from TLS will be directly applicable to NMLS. The self-contained instrument landing problem is an extremely difficult one. The risks involved in achieving a true solution are high, but acceptable, because the derived capability will be militarily attractive and rewarding.

ECCM FOR TACTICAL LANDING

An EW vulnerability analysis of the NMLS is underway. The results of this analysis and subsequent field tests will be used to derive ECCM requirements for the Army tactical version of the NMLS.

AIR TRAFFIC MANAGEMENT

GENERAL

An air traffic management system is required to facilitate the safe, orderly, and expeditious movement of cooperating aircraft in the tactical area of operations, and to enhance interface with other airspace users. It consists of air traffic management procedures and equipment that allow the commander flexibility in the employment of his combat assets. The movement of all aircraft (during departure, enroute travel, approach to terminal, and landing) will be regulated as expeditiously as possible with minimum restriction to aviators under varying conditons of weather and visibility.

To provide an air traffic management system for aircraft use under conditions that prevail in the battlefield (i.e., high air defense threat, nap-of-the-earth flight, and high flexibility of use in poor weather and visibility) is a very challenging problem. Under the present system, the see-and-be-seen principle is the primary hazard avoidance technique. This principle requires constant vigilance by aircraft crews, since

controllers can only provide alerting information to cooperating aircraft, based upon voice position report data evaluation. The system becomes saturated at very low aircraft densities during poor weather conditions. A system of flight operations centrals and terminal control facilities tied together by voice radio techniques is now standard in the Army.

CONCEPTS AND APPROACH

The next level of air traffic management to be introduced into the Army will use real-time aircraft position data obtained from radar in conjunction with aircraft position based upon voice reporting. Current Army aircraft management principles and policies, user requirements, and restrictions imposed upon aircraft operations in the Corps area by the high threat environment have resulted in the present Army concept. Under this concept, air traffic control flight clearance under Instrument Meterological Conditions in the Corps area is to be initiated with and received from the Flight Operations Center via the Air Force Control and Reporting Center. From Division rear, forward to the FEBA, the Army plans to furnish Air Traffic Management services via the Flight Coordination Center and the nondirectional beacon. An inconclusive area, still a technical barrier in air traffic control technology, is air-ground-air communications under NOE flight conditions. Further development is needed to determine the best technical approach to maintaining data communication over the horizon with low altitude aircraft.

CURRENT AIR TRAFFIC MANAGEMENT EQUIPMENT

Current engineering development efforts for the terminal subsystems of the Air Traffic Management System include the visual control facilities, AN/TSW–7A and AN/TSQ–97. The AN/TSW–7A is a three-man control tower used at major tactical airfields. DT II/OT II testing was completed in FY75 and the planned IOC data is in FY78. Present antennas furnished with the AN/TSW–7A are extremely heavy, bulky, costly, and hard to erect. Therefore, any AN/TSW–7A's built in the future will use a new antenna which is smaller, costs less, and still meets required performance characteristics. The engineering development of the AN/TSQ–97, a manportable control facility to be used at forward tactical airfields, was completed in FY74. In FY75, low-rate initial production was started. The planned IOC date is FY77. To improve the Army's instrument approach capability at tactical airfields, a Product Improvement Program for the GCA Radar AN/TPN–18 was initiated in FY75 to reduce maintenance costs by improving radar reliability and maintainability. The modified units are to be fielded in FY78.

The key elements in the next generation Air Traffic Management System are the Flight Operations Center (FOC) and the Flight Coordination Center (FCC) augmented with area surveillance radar. The Air Traffic Management system concept will be developed and validated jointly with TRADOC under a proposed Enroute Facility LOA which is being staffed through TRADOC Headquarters. Emphasis on concept formulation will be based upon experimental configurations to determine the best technical approach. Facilities will be fabricated to permit user/developer in-house evaluation to define operational interface and procedures. The FAA is in the early planning stages for the development of a new low-cost airport surveillance radar. Initial effort will be based upon a review of FAA and other service developments to determine whether a joint development program can satisfy both Army and other user requirements.

The program may necessitate the use of operations research and system analysis techniques in an air traffic management man/machine interactive simulator. The simulator can be utilized to simulate and analyze TRADOC approved scenarios to obtain Army Air Traffic Flow data which is required by the system engineer in designing an Air Traffic Management System. Typical examples include: aircraft traffic flow data, mission times, number of aircraft flying during busy periods, and potential collisions. Separation requirements data for closely spaced helicopters performing approaches and landing in a tactical environment under conditions of IMC can be generated by the simulator. This is a totally unexplored ATM problem unique to helicopter operations, particularly as applied to tactical, airmobile scenarios.

In response to newly emerging concepts expressed in Draft FM1-60 "Army Air Traffic Management in the Combat Zone" (September 1975), a program was being initiated in FY76 to provide Very Lightweight Air Traffic Management Equipment that will allow ground personnel to determine the range and bearing from them to selected aircraft. With this information they will be able to assist aviators by giving them steering and distance information when required. Examples of such use are: vectoring aircraft to an LZ

or Forward Area Resupply and Refueling Point under poor visibility or darkness conditions; sequencing flights into an area in the most expeditious manner; monitoring traffic in he vicinity of an airfield. The equipment will range in size and capability from very light units which work with one aircraft at a time up to larger units, about 10 cubic feet in size, which would be used at Division Airfields to track large numbers of aircraft. An example of a very lightweight unit would be a hand-held device with which one man can vector a medevac helicopter to an isolated position to pick up a wounded man.

This equipment will operate by interrogating the aircraft's existing transponders, thereby not requiring new or additional equipment in the aircraft. The various equipment will be compatible, and functional modules will be interchangeable in order to reduce maintenance and logistics costs.

LONG-TERM ATMS

Programs utilizing the concept of ICNI/TDMA (Integrated Communication, Navigation, and Identification/Time Division Multiple Access) are being examined for their potential capability to provide more effective Air Traffic Management Systems in the Post-85 time period.

This concept of combining many of the functions now performed by separate systems in a single multifunction system will provide such services as precise position location, data communication, IFF, and collision avoidance. This system concept is uniquely suited to implementation by stages. Once the basic system is developed, additional functions can be realized – mainly by software changes. Growth capability can thus be tapped in accordance with future user needs and funding constraints. ICNI could provide many advantages to the Army:

- Accessibility – ICNI will provide a common relative grid where data of common interest may be transferred among all interested parties with a maximum time lapse of only a few seconds. This capability for rapidly establishing and exchanging position and identity will prove invaluable in future tactical operations involving a mix of friendly and enemy aircraft and other highly mechanized weapon systems.
- Commonality – Multiple functions can be accomplished with common basic modules using a commonly shared RF channel.
- Security – The digital structure is well suited to the application of anti-jam and security measures.
- Performance – The use of common equipment to perform multiple functions increases the effective payload of a given aircraft.
- Logistics – The reduction in the number of electronic equipment required by this approach and the possibilities for simplified (semi-automated) diagnostics and repairs greatly ease the problem of logistics and support.

By FY77, the feasibility of a first-generation ICNI system combining position location and data transfer functions will have been established by a joint development, test, and evaluation program by the Army and Marine Corps. This first-generation ICNI is known as PLRS and represents an austere implementation of the ICNI.

ECCM FOR PLRS/ICNI

An initial theoretical EW susceptibility analysis of the PLRS has been completed. EW vulnerability data has been derived for a sensitivity analysis of PLRS links in an EW environment. This data will be useful in establishing operational tactics for the master units and user units. ECCM requirements for the PLRS development specification have been prepared. Efforts were initiated in FY76 to establish basic ground work for investigating ECCM techniques and requirements for future ICNI systems.

If PLRS proves to be the most cost-effective candidate for a future post-85 Air Traffic Management System, the growth capability of PLRS can be exploited by a product improvement program starting in the early 1980s.

ENVIRONMENT SENSING

GENERAL

Environment sensing provides for sensing the environment external to the aircraft, as necessary, for safe operation of the aircraft and achievement of tactical goals. It includes equipment designed to provide a functional capability in radar altimetry, terrain avoidance/following, obstacle avoidance, collision prevention, formation flight, high resolution groundmapping, moving target detection and weapon pointing, weather warning, and assistance in making

remote area landing approaches. Anticipated technology developments will enable increased levels of environment sensing capability in the advancing timeframe as reflected in the approved requirement documents. Environment sensing technology barriers are achievements of severe performance requirements (resolution, range, fields of view, etc.) within the practical limitations of size, weight, cost, etc., imposed by the Army's small helicopters.

RADAR ALTIMETER

There is a need to provide both fixed and rotary-wing Army aircraft with a standard lightweight, militarized absolute altimeter that the Army can afford. This altimeter must provide accurate aircraft height above the terrain and high/low altitude warnings to assist the pilot/aircrew, particularly in low-level helicopter operations. This formal Army need is expressed in an approved MN (CARDS 533c). The on-going program to meet this Army need is an ODDR&E pilot "Design to Cost" program, designed to provide the required altimeter at an acquisition and total ownership cost that the Army can afford. Two parallel engineering development contracts were implemented in November 1973, with a competitive Government evaluation and fly-off scheduled for late FY75. To preserve the $3,500 design-to-cost goal (FY72 dollars), the entire development specification consists of essentially only five parameters (altimeter range, accuracy, frequency, size, and RAM). Source selection for initial production will be based, in part, upon demonstrated contractor ability to meet all the essential and as many of the target parameters as feasible within the $3,500 cost goal. Based on DT II/OT II test results, an initial production contract has been awarded to Honeywell Corporation. This multi-year contract will provide 2000 systems with delivery starting in the 4th quarter of FY77 to satisfy OH–58, UH–1, CH–47, and AH–1 aircraft requirements.

MULTIFUNCTION ENVIRONMENT SENSOR

A need exists for a multifunction environment sensor to provide Army aircraft of the post-1980 timeframe with a capability to perform low-level flight under night and adverse visibility conditions. The current technology base for such a multifunction capability is extremely limited, particularly in the individual areas of obstacle detection, collision avoidance, and all-visibility formation flight. The near-term objectives are to build up the technology base in each of the individual sensor areas and the area of multifunction sensors to a point where the technical feasibility of a multifunction environment sensor can be demonstrated and a qualitative spectrum of alternatives prepared. Establishment of feasibility for a full multifunction capability is forecast for FY81, with an IOC of approximately 1990. Individual sensor rake-offs are anticipated with earlier IOC dates. A major limiting problem in the area of low-level flight is the detection and avoidance of small wires and cables. A scanning CO_2 laser system, the Laser Obstacle/Terrain Avoidance Warning System (LOTAWS), is being actively pursued and appears to offer strong promise as a potential solution to this very difficult problem of wire detection, with a secondary capability for terrain following. In FY77 additional exploratory development will be continued to add other functional capabilities to LOTAWS, including range-finding and target designation, with a view toard providing a more cost-effective total system capability. An EW vulnerability investigation of the LOTAWS is underway. This effort will provide the basis for formulating ECCM requirements for future LOTAWS models. Technique investigations of alternate obstacle avoidance systems have identified the use of charge coupled devices (CCD's) as having considerable potential as a lower cost solution. In FY77 exploratory development of the CCD approach will be continued toward the fabrication of a Wire Obstacle Warning System (WOWS). Advanced development and successful MASSTER tests have been completed on a formation marking light kit, utilizing electroluminescent panels which are capable of covertly providing a nighttime formation flight capability. An exploratory development effort to exploit the technology inherent in the Army developed Collision Warning System (CWS) and Proximity Warning Device (PWD) to provide additional functions for homing, rendezvous, formation flight/stationkeeping assistance, and landing assistance will be started in FY77. This effort, the multifunction transponder, will have as its aim providing all of these functions in a single multifunction unit configuration. This will result in considerable reduction in size, weight, and cost as compared to current capability, where each function is performed by a separate black box.

PRODUCT IMPROVEMENT PROGRAM

A Product Improvement Program directed towards reliability improvement and technical update of the initial production Proximity Warning Devices will be

conducted in FY77. Basis of PIP are initial production models declared excess to Ft. Rucker's requirement. These models will be improved and subsequently distributed to meet PWD requirements at Forts Hood, Campbell, and Bragg.

Results of second quarter FY75 In-Process-Review of the Collision Warning System established that a requirement for this system did not exist. Consequently, HQ DARCOM directed that developmental effort of this system be terminated.

INSTRUMENTATION

GENERAL

Instrumentation provides for the display of information to the pilot on the status, condition, and trend of essential parameters and subsystems necessary for the safe operation of the aircraft system and the achievement of tactical goals. This information includes data on flight, airframe, and subsystem parameters, navigation and radio aids, landing aids, etc. The display of computed director information for specific functions or maneuvers such as IFR, steep angle approach and landing, and terrain-following would also be accomplished using aircraft instrumentation. The majority of instruments in today's helicopters are based on the technology of fixed-wing instruments that do not address the special requirements of rotary-wing aircraft. Although early development work has been done for specific helicopter instrumentation (such as vertical format engine indicators, flight directors, head-up displays, and emergency warning indicators), there has been a lack of formal requirements documents and funds to procure, test, and evaluate the potential of these systems.

The basic instrumentation R&D objectives are to provide instruments and displays best suited for helicopter operations during day, night, and instrument flight conditions. These objectives support aircraft low-level operations, observation and fire support missions, air traffic control, takeoffs, hover, and approaches and landings. When earlier fixed-wing work provides a viable base for expansion into the rotary-wing regime, fixed-wing systems would be adapted, modified, and expanded as appropriate to the specific application.

The current instrumentation programs are as discussed below:

- *Control Display Unit* – The CDU will be programmable and compatible with Air Force Multiplexing Standard MIL-Std-1553. The CDU is intended to replace control units for single subsystems such as ARC–164, –114, LORAN or Doppler Control Unit or to be programmed to function as a control unit for several units such as the DIMAP core system. The panel will employ an alpha-numeric display and multi-legend display switches capable of operating under extreme cockpit illumination conditions. Growth capability will be provided through the use of modular packaging of the electronics. Work will start in FY77 using the technical and procedural results of the I/O Panel Display for Digital Modules Avionics Program (DIMAP). Advanced development models will be developed to demonstrate full system potential by FY79. The operational impact of this effort is to greatly reduce the console space requirements and simplify operation.

- *Vertical Format Solid State Displays* – These displays will be modular and can be used singly or in combination to display engine or certain flight parameters, using Dot-Matrix techniques such as light emitting drodes, light emitting films, or liquid crystals. The formats will be programmable via an integrated memory card or from an external source. This program will be initiated in FY77 to procure exploratory dev. models.

- *RMI/HSI (Digital Solid State)* – This effort will start in FY77 with a feasibility investigation of a solid-state radio magnetic indicator/horizontal situation indicator to serve as a digital replacement for conventional electromechanical indicators.

- *Programmable Symbol Generator and Multi-function Display* – The PSG/MFD procured in FY76 was used to evaluate the DIMAP core system and will continue in FY77 with contractor field support for integration of the equipment into the test aircraft after the DIMAP bench testing. An additional stroke-written display plus software necessary for interfacing the PSG with a teletypewriter enabling ground test and verification of our software program for varying display formats will be started in FY77.

- *Low Airspeed System* – Flight tests of three off-the-shelf low airspeed systems commenced in January 1976 at the US Army Aviation Engineering Flight Activity (AEFA). This program is aimed at extending the airspeed input available to the pilot to include the low 0–40 knot range. Airspeed inputs to the lightweight doppler navigator system will support its operation when it is in the Air Mass Reversionary Mode. Based on AEFA flight tests in FY76 a formal requirement, LOA or ROC, will be formulated jointly by TRADOC/ECOM as the basis for development of a low airspeed sensor/display suitable for Army-wide applications. This system will provide the pilot with airspeed data over the entire airspeed range of the aircraft, no longer requiring the present airspeed input from the pilot-static system.

- *Flight Director System* – An in-depth matrix analysis of existing off-the-shelf 3-cue Flight Director Systems (FDS) revealed that no one system totally covers the entire rotary wing flight regime and each system used a different approach for both software and hardware to solve command cue information. These differences were distinct enough to merit a flight test program using all systems.

  Development specifications for the 3-cue system have been completed and work is presently in progress to complete a set of specifications for a 4-cue flight director system which can be used for low-speed flight (below 40 knots), steep approaches to a hover, and during hover.

  By reducing or avoiding proliferation of FDS types logistics will be minimized and unit cost greatly reduced. Funds permitting, plans are to develop a standard FDS to proof the aforementioned 3 cue and 4 cue FDS specifications. This effort will validate the specifications and provide a sound basis for achieving maximum commonality of Flight Director Systems in Army aircraft.

SURVEILLANCE AND TARGET ACQUISITION

GENERAL

Surveillance involves the detection of weapons, personnel, vehicles and fixed installations; the conducting of radiological surveys, and the assessment of damage and terrain conditions. Target acquisition is a refinement of the surveillance process involving the location of selected targets with sufficient accuracy so that they may be taken under fire by weapons. To overcome the obstacles of distance and interfering terrain, a large part of the surveillance and target acquisition mission must be accomplished by aerial means.

The Army's capability to perform aerial surveillance is presently provided by the OV–1D Mohawk system. This second generation Mohawk uses interchangeable, high-resolution IR linescan and sidelooking radar sensors to provide a day/night surveillance capability. This capability is good for intelligence applications except for lack of an air-ground data link (still under development) to permit ground viewing of sensor data in real time. However, the OV–1D Mohawk provides only a very limited target acquisition capability. Its principal deficiencies for this function, beside the lack of real time data on the ground, are a relatively slow search capability and low accuracy in locating observed targets.

SURVEILLANCE AND TARGET ACQUISITION REQUIREMENTS

Improvements in airborne surveillance and target acquisition capabilities, beyond those provided by the OV–1D Mohawk, are required which will:

- Permit detection of targets under the cover of foliage.

- Increase the speed with which an enemy area can be covered, and in which changes in enemy activity can be detected, including means for transmitting airborne sensor data to ground receiving stations in real time.

- Improve the resolution of day/night sensors for better target identification.

- Permit, in a jamming environment, the real-time transmission of surveillance and target acquisition data.

- Enhance the ability to penetrate the enemy for purposes of surveillance, target acquisition, and target designation.

- Permit the location of targets to be precisely determined, so that weapons can be effectively directed to destroy the targets.

- Permit ground targets that are designated by a laser beam to be tracked by an airborne seeker.

SURVEILLANCE AND TARGET ACQUISITION PROGRAMS

These required improvements are the objectives of the following programs:

- *Stand-Off Target Acquisition System* – An advanced development SOTAS underwent a demonstration test at the Hunter-Ligget Military Reservation to measure and evaluate the applicability of the system to detect and locate moving ground targets and to predict the target's future location in a timely manner so as to provide for target engagement by candidate supporting weapon systems. Data from this demonstration test have been analyzed and preliminary reports of findings have been prepared. The testing of the SOTAS was coordinated with the Air Force in a joint multilateration radar demonstration at the White Sands Missile Range. The purpose of this demonstration was to determine the feasibility of using airborne MTI radars, as in the SOTAS, in conjunction with a DME guided weapon to detect, track, and strike moving ground targets. SOTAS plans for FY76 and FY77 call for user evaluation of the system and for continued investigation into an improved radar and data processing capability.

- *Stand-Off Fixed Target Detection Radar* – While many proven techniques exist for detection of moving targets, the detection of stationary, tactical ground targets presents a difficult problem. The SOFTAR program, initiated in 1975, is aimed at the development of techniques for the detection and classification of tactical ground targets at stand-off distances (10–30 km) by means of radar on a low performance platform, such as a helicopter.

  The planned work includes a review of existing target signatures, additional precision (target on a pedestal) measurements, airborne target measurements at several environments. A study will be made of techniques suitable for enhancing the radar return from hard targets as compared to the clutter background, and of techniques for target identification. Critical components, such as processors, will be built and tested. Recommendations will be made for the design of a stand-off airborne radar with fixed target detection capability.

- *Millimeter Surveillance Radar for the Army RPV* – A contractual effort with Norden Division of United Technologies Corporation was awarded in FY76 for the design and fabrication of a 3.2 mm (95 GHz) surveillance radar for adverse weather RPV operation. Funding for the program is being provided by the RPV Weapons System Manager, AVSCOM. The radar will provide high resolution ground mapping, fixed target enhancement utilizing polarization diversity, moving target indication, and real time digital processing. The brassboard radar provides forward coverage of approximately ±20° over a 1 km to 3 km range swath. A range resolution of 3.0 m and azimuth resolution will be provided.

  The performance objective is to detect, recognize and locate with a high degree of confidence fixed and moving targets, such as artillery batteries and tanks in a clutter and multi-target environment. The advantage of the 3.2 mm radar wavelength is the ability to provide real-time high resolution maps with rapid update in adverse weather. The radar design provides for a high detection probability at 3 km on a 30 m^2 target in both clear air and 120 m visibility fog. In 4 mm/hr of rain, radar range will be limited to 2 km, allowing a 1 km to 2 km range swath.

  The brassboard radar is being fabricated utilizing, to a large degree, existing components in order to demonstrate the utility of the radar concept. The radar design is compatible with mini-RPV physical constraints, such that eventual radar size, weight, and power requirements will allow radar installation aboard a mini RPV with a predicted weight of 35 lb for the radar.

- *Airborne Weapons Locating Systems* – AWLS is planned as a multisensor system capable of accurately locating enemy indirect fire artillery, rockets, and mortars. Candidate sensors now being examined include techniques such as DIMODE (Discontinuity Modulation Effect), high-resolution millimeter radar, IR flash detection, and laser gun-effluent detection.

These ongoing exploratory development efforts will culminate in the initiation of an advanced development version of AWLS in FY77. This system is being planned to provide the following basic characteristics:

- Long Range Stand Off
- Wide Azimuth Coverage
- Firing and Non-Firing Weapons Location
- High Location Accuracy
- Low False Alarm Rate
- Real-time Data Presentation

- *Photographic Systems* – A product improvement proposal has been initiated to modify the Mohawk Photographic Surveillance System KS-113 to provide for night covert photographic surveillance with a minimum of flash radiation. A high quality image intensifier will be inserted between the shutter assembly and the camera back of the KA-76A camera utilizing the present camera control system.

The laboratory model for a small, lightweight rapid access processor/viewer/printer will be completed in FY76. This PVP is envisioned as a ground support system to provide a "quick look" at 250 ft of small format aerial imagery from the RPV photo system immediately after landing.

The operational capability, reliability, and ease of maintenance of the ES-38 Mobile Photo Lab will be improved by increasing the output of the processors, adding a rapid access reversal color system using ECOM chemistry, redesign of component problem hardware, and improved space heating, ventilating, and air conditioning. A new silver recovery system will be incorporated into 138 shelters in FY76, and will provide the Army with a means for economically recovering the silver removed from the photographic emulsion as a result of the processing procedure. It will also reduce markedly the pollution effect of silver in the photographic effluent.

- *Data Transmission System* – A Data Transmission System, AN/USQ–49, is being developed to transmit surveillance data from the Mohawk OV–1D to the ground in real time. A feasibility model of an AIDATS (Army In-Flight Data Transmission System) for SLAR data was fabricated and flight tested (DT I/OT I). An engineering development effort is underway to provide a technical base for an LRIP of a fully qualified AIDATS air-to-ground SLAR data transmission system in FY77. IR data link and airborne relay developments are also planned.

- *Dry Processing for AN/APS–94D Radar* – Presently production prototypes of a dry silver film processor are being constructed and tested for installation in the AN/APS–94D radar. Dry processing will provide improved radar imagery while eliminating the problems inherent with wet processing techniques. Production is planned for FY77.

- *Interim (SLAR) Data Link* – A UHF data link formerly used with the AN/APS–94C/OV–1B MOHAWK aircraft has been modified to be compatible with the AN/APS–94D/OV–1D aircraft and was deployed to Europe in 1975. It is similarly planned to deploy the same modified data link to Korea for use with the AN/APS–94D radars when they are fielded during 1976. This data link will be replaced by the AN/USQ–49 data transmission system when it becomes available.

- *Laser Designator/Tracker System* – This system with the nomenclature AN/UAS–8 is completing development and consists of two separate equipment, an Airborne Laser Tracker (ALT) AN/AAS–32 and a Lightweight Laser Designator (LWLD) AN/PAQ–1. The designator is used by forward observers to designate area targets. The tracker is installed in mission aircraft and coupled to a visual display to guide the aircraft to the target being designated. The ALT and associated LWLD went to DT II/OT II in FY76.

- *Handheld Laser Rangefinder AN/BVS–5* – The HHLR is under development to provide the target acquisition needs of both infantry and the artillery forward observer. For the infantry, the low weight of this equipment (5 lb) allows handheld operation; for the artillery requirement, a tripod will be employed. The clear day ranging distance of 10 km permits a high probability of an accurate first round delivered on

target. The HHLR will complete DT II/OT II in FY7T with a decision concerning production early in FY77.

- *Aerial Radiac System – The Aerial Radiac* System, AN/ADR–6, now in development, will perform measurements up to 1,000 ft above terrain at 0.5 Mach, based on ground radiation levels of 1 to 1,000 rad/hr. DT II/OT II will be completed with LRIP of equipment planned for FY77.

- *Remotely Piloted Vehicles* – The precise location of targets such as troops, tanks, and other vehicles as well as fire adjustment are the objective of a surveillance and target acquisition RPV development program under the cognizance of the RPV Weapons Systems Manager, AVSCOM. Support programs exist in the areas of navigation, aerial photography, laser designation, and command and control data transmission, processing and display.

Four mini-RPV airborne vehicles with TV or photographic sensors and one with laser designator were feasibility tested by ECOM under the RPAODS program. The major portion of this program was completed in FY75. The final portion, wherein a mini-RPV designated a tank target with a laser was successfully completed in October 1975 with a direct hit of a CLGP round on the target tank.

The RPV WSMO is currently developing a mini-RPV system called AQUILA which uses photographic and TV sensors and laser designator. This system will be operationally tested by TRADOC to develop requirements for a tactical mini-RPV.

Further developments of mini-RPVs are planned to include night sensors, improved anti-jam data links using techniques such as fast frequency hop, beyond line-of-sight operation and multiple mini-RPV operations.

ECCM FOR SURVEILLANCE AND TARGET ACQUISITION

The following are specific systems and functional areas under investigation:

- *Stand-Off Target Acquisition System* – The EW vulnerability of the SOTAS is currently being assessed. Theoretical analyses have been completed and preliminary electronic countermeasure field tests have been performed. Data analysis is continuing.

- *Side Looking Airborne Radar* – The EW vulnerability of the AN/APS–94D is currently being evaluated and the system is being modified to include appropriate ECCM. Preliminary ECM field tests of the unmodified system have been performed. Additional tests and evaluation of the modified system are scheduled for FY77.

- *Data Transmission System for the OV–1D Mohawk* – A program to evaluate the EW vulnerability of the AN/USQ–49 has been initiated. The goal is to evaluate the EW vulnerability on a mission basis and determine appropriate ECCM. This program was initiated during the 3rd quarter of FY76.

NIGHT VISION SYSTEMS

GENERAL

Emphasis on aircraft survivability has given impetus to the need for night vision devices that will allow Army aircraft to perform their missions at nap-of-the-earth altitudes during darkness and periods of reduced visibility.

The primary requirement for airborne night operations is to enable the pilot to conduct the flight operations required by the mission and the copilot/gunner/observer to perform the mission function as well as providing navigation assistance to the pilot.

Night vision devices provide the visual contact necessary for the pilot to fly; however, other avionics will be necessary to execute required night scenarios. In addition, airborne night operations may include surveillance, target acquisition, and fire-control capabilities to meet other aircraft mission requirements.

NIGHT VISION GOALS

The basic R&D goals for night vision equipment for Army aircraft are:

- Determine the system specification for pilot night vision.

- Develop a sensor that will, with interchange of appropriate subassemblies, afford maximum commonality of airborne night vision equipment.

- Develop search effectiveness equipment that will improve target acquisition.
- Develop a family of displays for night vision systems (pilot, observer, gunner) to maximize information transfer from sensor to operator.
- Develop improved design concepts to reduce current sensor weight and sophistication, while improving reliability and maintainability characteristics.
- Develop standard night vision equipment configurations for use on future aircraft, thus minimizing integration impacts on both the airframe and night vision equipment.

Attainment of these goals requires close coordination among the DARCOM R&D activities involved.

NIGHT VISION PROGRAMS

Since the emergence of airborne far-infrared equipment developed under the SEANITEOPS program, significant advances have been made in system performance, weight, reliability, and maintainability. The AN/AAS–25 (PINE), developed for the AH–56, was produced by the Air Force in considerable quantity. The AN/AAS–25 represented the state-of-the-art until the Army development of the Universal Far Infrared (UFIR) system modules.

The concept for systems development is to use the Universal Far Infrared system modules as much as possible. UFIR is a general development of modules (e.g., scanner, detectors, electronics) that are common not only to airborne night vision systems but also armor, anti-aircraft, and crew-served anti-tank weapon night vision systems. The UFIR modular approach allows per-unit-cost reductions by achieving a high production base. The impact of the modular concept on weight and cost is shown in figure AV–3. In addition to the reduced sensor costs, the performance of the modular FLIR shown in figure AV–3 is twice that of the AAS–25. The installed weight includes displays, gimbals, stabilization, etc.

A principal non-common component is the objective lens which is designed for each application, for example, gunner and pilot. New design techniques, optical materials, and fabrication methods are being investigated to reduce the present 10–20 percent portion of the sensor cost (fig. AV–3) attributable to the objective lens.

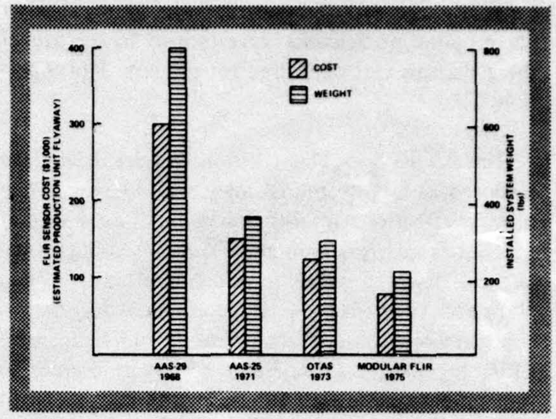


Figure AV–3. Trend of high performance sensor cost and system weight.

Currently under development are three candidate design concepts that will provide sensors adaptable to both wide-field viewing as well as surveillance applications. These approaches are being pursued to establish the most desirable design approach for meeting the current requirements. These systems are being developed to achieve commonality to meet all requirements in the Army (combat vehicles, airborne, etc.).

In FY75 a major Army test program was conducted by CDEC. This program (43.7, Clear Night Defense) was structured to validate the night vision requirements for AAH. A Pilot Night Vision System (PNVS) and Observer Target Acquisition System (OTAS), developed by the Army for the New Initiative Aerial Scout, was mounted on an AH–1G (OPTIC I) and tested at CDEC. The OPTIC systems provided wide-angle imaging for the pilot to enable low-level operations and achieve detection/recognition ranges with OTAS commensurate with those required in the AAH and ASH requirements. Results of this test indicate that target acquisition ranges in excess of those required by AAH were achieved. The results of the CDEC test validated the night vision requirements.

A second aircraft system (OPTIC IV), composed of another residual wide field of view pilots night vision system and a new UFIRS module target acquisition system on an OH–6C, was assembled for follow-on tests at CDEC. The AH–1G (OPTIC) and the OH–6C (OPTIC IV) demonstrated fire team tactics and aircraft to aircraft target handoff at night. The observer/gunner acquisition systems demonstrated a standoff capability outside of the threat weapons and the pilot night vision systems showed a

capability for nap-of-the-earth flight at night. User player pilot participants were trained in the use of these systems and were used for primary data collection.

The AN/PVS–5, Night Vision Goggles, have been accepted as interim pilots' night vision device. They provide effective nap-of-the-earth flight assistance at light levels quarter-moon and above. When the probability of reduced visibility, which also limits goggles usefulness, and darkness are considered together, a considerable advantage accrues to the more expensive FLIR together, a considerable advantage accrues to the more expensive FLIR sensors as they are light level independent and have better atmospheric penetration capability. This advantage in use vs. sensor cost is shown in figure AV–4. The trend has been to the FLIR sensor for those missions which cannot depend upon a rising moon but a product improvement program is being initiated to configure the goggles for airborne application and to introduce specific performance improvements that will enable their effective use for NOE flight in starlight. This increase in their operational utility, figure AV–4, would allow a considerable cost savings in PNVS applications as not every mission aircraft would require a sophisticated FLIR sensor.

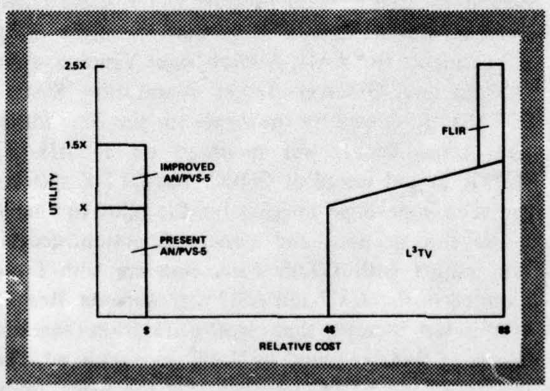


Figure AV–4. PNVS utility vs. cost.

Development of a family of airborne night vision components that can be configured to meet the requirements for airborne night vision is required in the approved ROC for Night Vision Systems for Army aircraft. This family of equipment can be available for parent aircraft to be fielded in the FY78 to FY82 timeframe. With the advent of third-generation intensifier devices and improved thermal technology in the early 1980s, a new generation of airborne night vision devices is envisioned that will have significant impact on system performance, figure AV–5, in improved standoff ranges with higher probabilities of target acquisition for the postulated threat weapons and wider fields of view for NOE flight in the late 1980 timeframe.

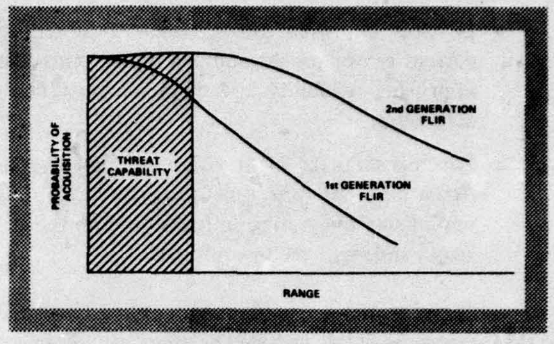


Figure AV–5. FLIR system performance.

Each aircraft has been shown by the CDEC tests to need two independent night vision sensors. A concept of optically multiplexing the sensors together for a cost and weight savings has been shown feasible yet retaining the necessary real-time imaging. Thus, an OTAS would have the wide field of the PNVS or vice versa.

EW VULNERABILITY EVALUATION OF NIGHT VISION DEVICES AND SYSTEMS

A program to evaluate the EW vulnerability of night vision devices and systems has been initiated. The goal is to evaluate selected equipment individually and in their systems role and recommend appropriate ECCM action. This program was initiated in the third quarter FY76 and will evaluate ground as well as airborne systems.

PRIORITIES OF TECHNOLOGICAL GOALS AND OBJECTIVES

GENERAL

Items are placed in priority order in accordance with following rationale, going from highest to lowest priority:

- Immediate needs of the Army are satisfied, in order of urgency of needs, emphasizing items that have firm requirements and adequate funding.

- Next generation of items are developed, again giving priority according to need and also amount of improvement obtainable.
- Attack barrier problems that can lead to major improvement and high payoff.
- Payoff and risk are considered throughout; that is, for equal risk, items with greater payoff would have higher priority.
- These priorities are based on the long-range objectives of this plan. Therefore, they will differ and should not be compared with other priority listings that are based on shorter term objectives, such as the RDTE 5-year program.

PRIORITIES

AVIONICS

- *AN/ASN-128 (Naviation Set, Doppler)* – To provide a lightweight self-contained navigation system.
- *AN/APN-209 (Absolute Altimeter)* – To provide a standard lightweight absolute altimeter that is economical and supportable.
- *Integrated Avionics Control System* – To provide developing Army aircraft with modern integrated controls for communications, navigation, and identification equipments.
- *PLRS* – To develop an Integrated Communication, Navigation and Identification system combining both position location and data transfer functions in one system.
- *AN/ARN-114 (Loran Airborne Navigation Subsystem)* – To provide an accurate positioning and navigation system that is not limited to line-of-sight conditions.
- *Tactical Low-Level Communications* – To provide a capability for reliable and secure communications during tactical low-level flight.
- *Multifunction Environment Sensor* – To provide the aviator with the capability to detect and avoid wires and other obstacles while flying low level.
- *Tactical Hover* – To provide the aviator with the capability to perform the bob-up, hover, bob-down maneuver under tactical conditions, at night in scout and attack type aircraft.
- *Satellite Navigation* – To address application of the Global Positioning System to Army needs, viewing this system as the follow-on to LORAN as the common positioning and navigation system.
- *Audio Processing, Distribution, and Isolation* – To provide new microphones, earcups, and accessory devices to improve aircraft and audio system performance under conditions of high ambient noise.
- *Microwave Landing System* – To provide a tactical landing system fully compatible with future US (civil and military) and international standard systems, designed to replace the current VHF/UHF Instrument Landing System and usable in remote field sites.
- *Night Navigation/Pilotage System* – To develop an integrated system for both pilot and copilot addressing the problem of accomplishing pilotage and navigation in the night, low-level environment.
- *Digital/Modular Avionics* – To standardize digital signal interfaces among aircraft avionic systems and ground/air interfaces, and provide the basis for modular design of Army avionics equipment.
- *Air Traffic Management Visual Subsystem* – To provide terminal tactical air traffic control facilities for corps and forward/remote areas.
- *Secure/Jam-Proof Communications* – To provide the capability and provisions for totally secure airborne radio communications systems.
- *Near-Term ATMS* – Development of Very Lightweight Air Traffic Management Equipment that will allow ground personnel to determine the range and bearing from them to selected aircraft.
- *Instrumentation Technology* – Development of modular integrated control/displays and solid-state instruments for application to Army aircraft.
- *Navigation Technology* – To sustain and expand the navigation data base and exploit emerging technology. Near-term emphasis is on integration of Doppler with LORAN and improvement in low-cost heading reference.
- *Lightweight Inertial Navigation* – To reduce cost and weight for next generation inertial

navigation system while retaining present system accuracy.

- *Tactical Landing Technology* – To sustain and expand the technology base required for future developments in landing guidance techniques and systems.
- *FOC/FCC* – To provide enroute air traffic control facilities in forward areas.
- *Long-Term ATMS* – Development of integrated multifunction system providing such services as precise position location, data communication, IFF, and collision avoidance.
- *Proximity Warning Product Improvement* – To update initial production model PWD declared excess at Ft. Rucker to meet PWD requirements at Forts Hood, Campbell, and Bragg.
- *Multifunction Collision Warning System* – To exploit Collision Warning System (CWS) and Proximity Warning Device (PWD) technology to provide additional functions for homing, rendezvous, formation flights/stationkeeping assistance, and landing assistance.

SURVEILLANCE AND TARGET ACQUISITION

- *Stand-Off Target Acquisition System* – To provide rapid wide-area surveillance and provide the accurate location of enemy moving targets.
- *Remotely Piloted Vehicles* – To provide precise target location for friendly weapons within range.
- *Data Transmission System AN/USQ–49* – To provide urgently required real-time data capability to an existing system, the Mohawk OV–1D.
- *Laser Designator/Tracker System* – To enable attack aircraft to rapidly locate, with a wide-scanning tracker, targets that have been designated by ground observers using the Lightweight Laser Designator.
- *Handheld Laser Rangefinder* – To provide infantry and forward observers a lightweight portable ranging device to considerably improve the opportunity for a first round hit on selected systems.
- *Aerial Radiac System AN/ADR–6* – To provide a capability for rapid survey of radiological fallout (Priority 1).
- *Mohawk Low-Light-Level Photo System* – To provide a covert means for taking night photographs with the Mohawk OV–1D.
- *Airborne Weapons Locating System* – To locate enemy weapons in both the firing and nonfiring mode.

NIGHT VISION

- *Pilot Night Vision System* – To provide a surveillance capability at night to meet the requirements of the AAH and ASH.
- *Modular Night Vision* – To develop a sensor that will, with interchange of appropriate subassemblies, afford maximum commonality of airborne night vision equipment. The modularized concept is a high-return investment that will reduce costs associated with R&D, logistics, and support by providing standardization of equipment.
- *High-Resolution Sensors* – To develop search effectiveness equipment that will improve target acquisition. High-resolution sensors generally require moderate to small fields-of-view. Automatic detection of targets will greatly reduce operator workload while increasing system effectiveness.
- *Night Vision Displays* – To develop a family of displays for night vision systems (pilot, observer, gunner) to maximize information transfer from sensor to operator. Sophisticated sensors require displays that do not limit performance while providing maximum utility with aircraft physical restraints.
- *Design Improvements* – To develop improved design concepts to reduce current sensor weight and sophistication, while improving reliability and maintainability characteristics to enhance overall mission effectiveness.
- *Standard Configurations* – To develop standard night vision equipment configurations for use on future aircraft. Minimizing integration complexity is a means to ensure compatibility of space, weight, and power requirements of night vision equipment with future aircraft.

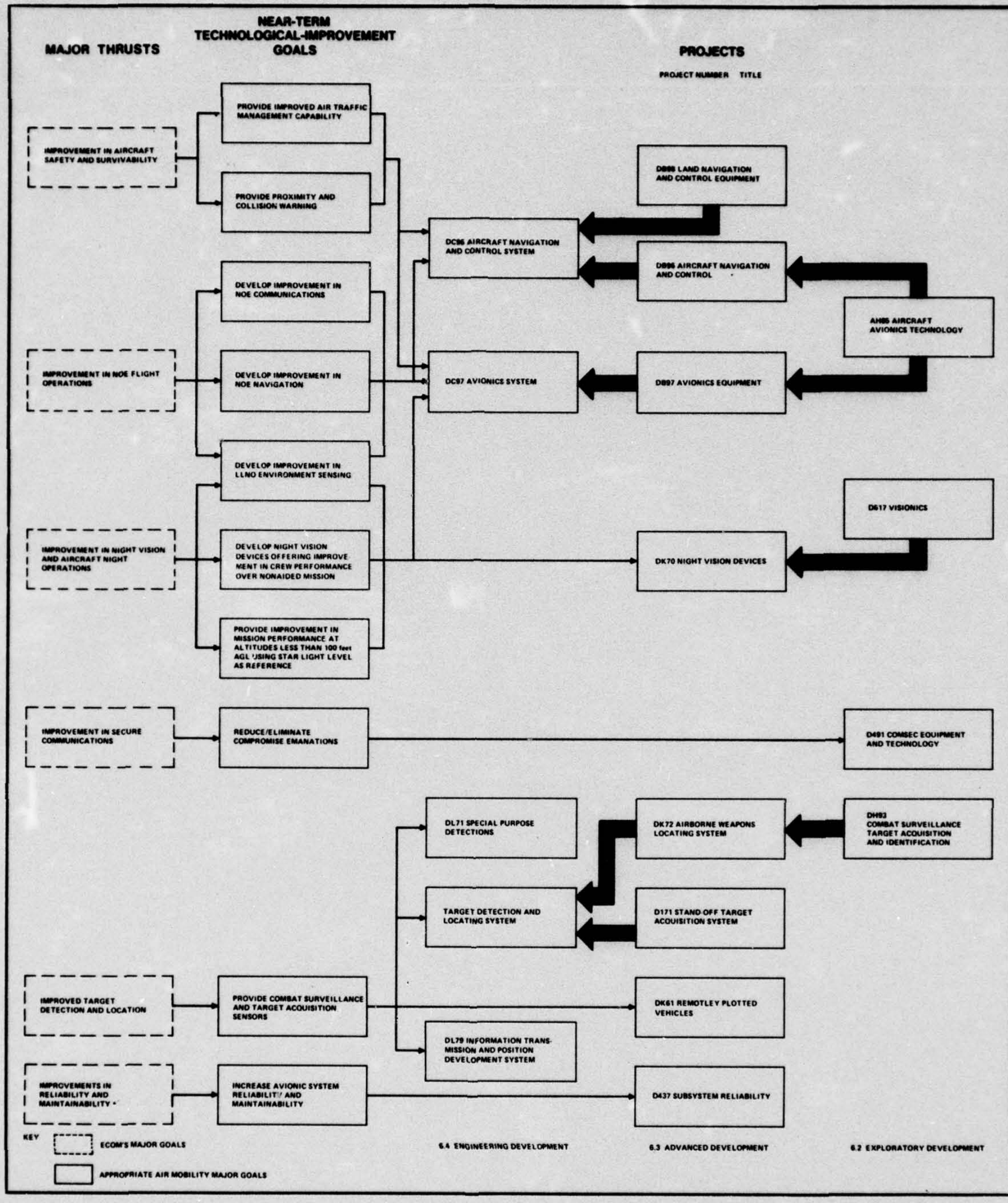


Figure AV–1. Research and development program flow diagram.

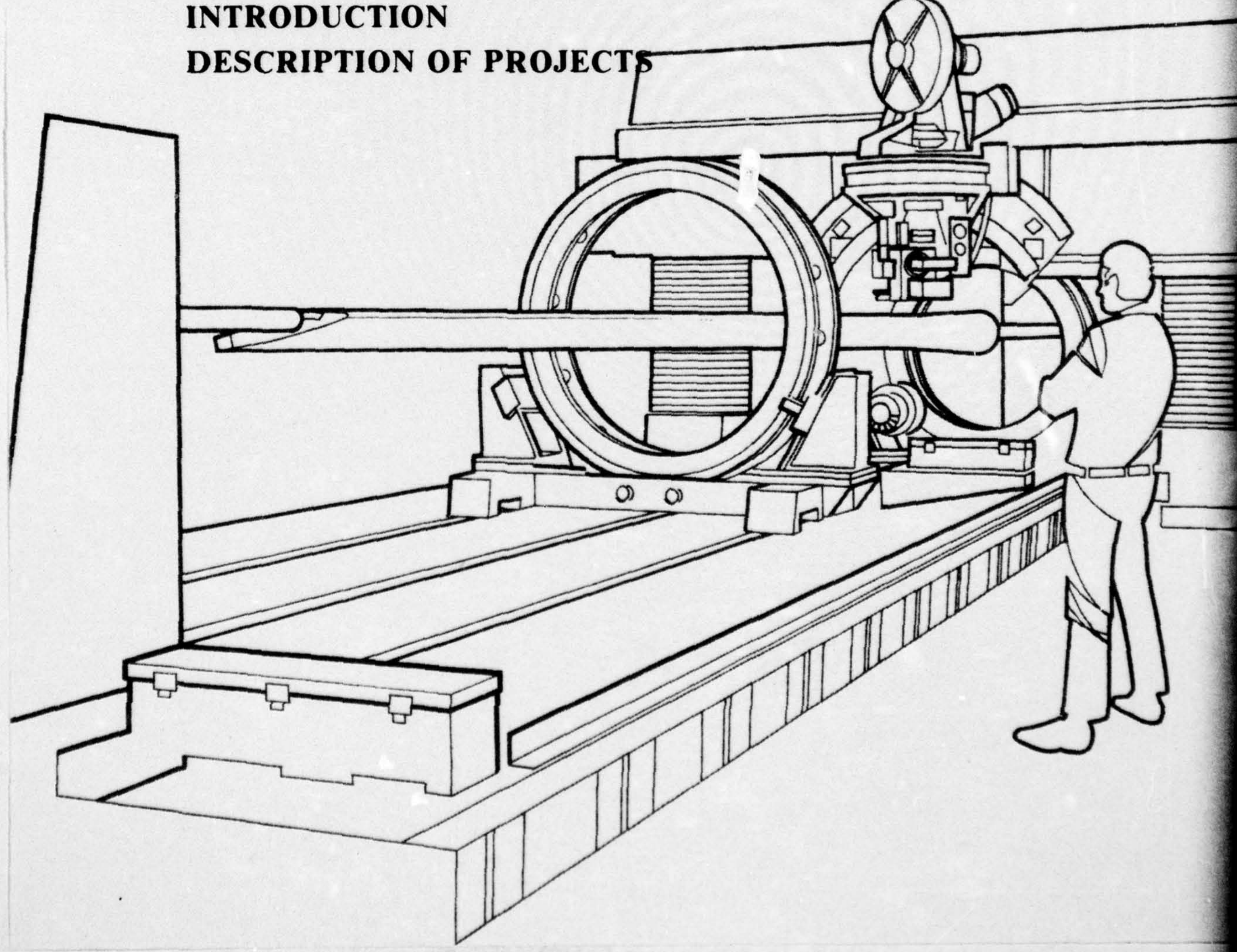
INTRODUCTION

TECHNOLOGICAL DISCUSSION

SHAPE CHANGING PROCESSES
MACHINING PROCESSES
JOINING PROCESSES
SURFACE FINISHING PROCESSES
COMPUTER-AIDED MANUFACTURING

TECHNOLOGICAL PROGRAM DIRECTION

INTRODUCTION
DESCRIPTION OF PROJECTS



Manufacturing Technology (MT) may be broadly defined as the complex of processes, methods, and techniques available for producing items of materiel. Efforts in the MT area provide for engineering measures required to investigate, evaluate, and adapt new or technological advanced manufacturing methods, processes, techniques, tooling, and equipment to ensure economic availability of materials, components, and systems. Efforts in MT may be undertaken during various phases of the systems acquisition process, but are commonly initiated during one of the two major phases, Engineering Development or Full-Scale Production.

Manufacturing technology efforts may coincide with certain efforts noted in other portions of this plan; for example, this occurs whenever a process for using a heretofore unused raw material is developed (e.g., casting of columbium alloys). It thus may be difficult, in some instances, to distinguish between a materials effort and a process effort . Other interfaces may occur between portions of this section and any of the various "hardware-oriented" sections such as Propulsion or Aircraft Subsystems.

AVSCOM MT efforts, termed Manufacturing Methods and Technology (MMT) projects, are currently executed under the aegis of the Production Engineering Measures (PEM) program and are funded by Procurement Appropriations. Efforts oriented toward an end-item undertaken during the development phase and directed toward finalization of the technical data package are executed under the Producibility Engineering and Planning (PEP) program and are R&D funded.

Manufacturing problems arising from insufficiently developed state-of-the-art technology are sometimes responsible for various failures in production buy items. Materials are often available that have characteristics for increased service life or other benefits, but the process for shaping these materials into particular forms is not sufficiently developed. A less desirable material is then substituted that results in decreased capability, reliability, or service life. Thus, MT efforts are intimately related with various product improvement efforts. The former assures development of the process by which the materials and design specified by the latter can be used in the manufacture of an item. Figure MT–1 presents a view of MT as it relates to other programs of interest.

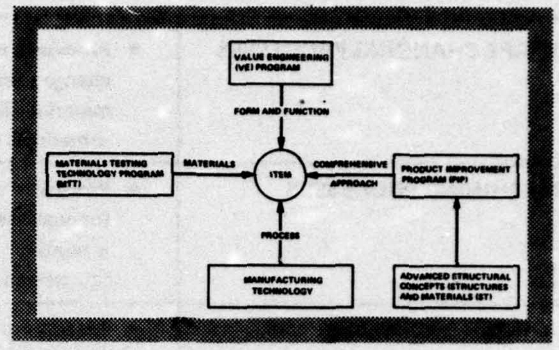


Figure MT–1. Relationship of item to certain basic programs.

The Technological Discussion subsection has been divided into the subdisciplines described in table MT–A. These divisions are logical for the purposes of this work, but are not necessarily mutually exclusive. For example, polishing is considered to be a surface-finishing process, although it could also be a machining process. In general, however, these categories are adequate to establish a structure for the different areas of manufacturing technology to be addressed.

Efforts in MT are often generic in nature and cannot readily be related to one specific aircraft system. Whenever possible, however, an attempt has been made to identify specific systems that would benefit from implementation of such technology and to translate performance requirements into MT requirements.

For a detailed explanation and description of various manufacturing techniques and processes, the reader is invited to study AMCP 706-100, "Design Guidance for Producibility."

TECHNOLOGICAL DISCUSSION

SHAPE CHANGING PROCESSES

GENERAL

Operations categorized as shape-changing processes are listed in table MT–B.

All of the processes listed are used to some extent in the manufacturing of Army aircraft. Processes such

TABLE MT–A
MANUFACTURING TECHNOLOGY SUBDISCIPLINE DESCRIPTION

SHAPE-CHANGING PROCESSES	• Process in which a raw material, either metallic or nonmetallic, is changed into its primary form for some selected part by "moving" material. Such an operation is relatively waste-free and is sometimes termed a "primary" fabrication process.
MACHINING PROCESSES	• Process in which a raw material is changed into its primary form for some selected part by removal of material. Such an operation is relatively wasteful and is normally termed a "secondary" fabrication process.
JOINING PROCESSES	• Processes wherein two or more pieces of material are joined by fasteners (mechanical joining), by creating metallurgical changes in one or more of the materials (metallurgical joining) or by the application of a chemical agent that creates a bond through use of a chemical interaction (chemical joining).
SURFACE FINISHING PROCESSES	• Processes used to ensure a smooth surface, achieve great dimensional accuracy, obtain aesthetic appearance or impart a protective coating.
ALTERATION OF PHYSICAL PROPERTIES PROCESSES	• Processes that change the physical properties of a material by application of an elevated temperature or by repeated stressing of the material.
COMPUTER-AIDED MANUFACTURING PROCESSES	• Processes wherein programmed numerical values, stored in some form of input medium, are automatically read and decoded to cause a corresponding movement of the machine that it is controlling.

TABLE MT–B
SHAPE-CHANGING PROCESSES

Casting	Piercing	Electrohydraulic Forming	Compression Molding
Forging	Swaging	Magnetic Forming	Transfer Moulding
Extruding	Bending	Electroforming	Injection Moulding
Rolling	Spinning	Powder Metal Forming	Callendering
Drawing	Stretch Forming	Roll Forming	Lamination
Squeezing	Torch Cutting	Shearing	Vacuum Forming
Crushing	Explosive Forming	Compounding and Preforming	

as squeezing, crushing, piercing, bending, roll forming, shearing, and torch cutting are well understood, sufficiently developed processes, and present no special problems and have not been included in future development plans.

The primary processes that, with further development effort, will effectively support future Army aviation systems are listed in table MT–C.

TABLE MT–C
PRIMARY DEVELOPMENT PROCESSES

METALLIC	NONMETALLIC
Casting	Casting
Forging	Compression Moulding
Extruding	
Explosive Forming	
Powder Metal Forming	

CASTING

General. All casting processes are basically similar in that the metal being formed is in a liquid or highly viscous state and is poured or injected into a cavity of the desired shape. Types of castings of special interest to Army aviation include die casting, investment casting, permanent mold casting, and precision casting.

Technological Voids. Turbine engine rotors for the compressor and power sections present the area of greatest possible gain in advanced castings. It has been shown that casting is a most economical method of manufacturing advanced turbine parts for both small and large airflow systems. Particular emphasis is required for the following developmental areas:

- Casting of high-temperature materials, capable of withstanding turbine inlet temperatures in excess of 2500° F as compared to the current 1800–2000° F.
- Casting of thin-walled blades, 0.010–0.015 in. thick, are required for small-turbine engine design.
- Development of casting techniques for titanium alloy components.
- Development of bicasting technique for radial turbine rotors with repeatability of material properties and minimum of 5000 hours of service life while operating in a gas turbine engine/gas generator environment.

Technological Discussion. Turbine inlet temperature increase from 1800° F to 2700° F for a 10:1 compressor pressure ratio would result in a decrease in specific fuel consumption while increasing the specific horsepower (hp/lb air/sec) from 125 to 210. This is a significant factor, which makes it imperative to develop high temperature castings. Columbium metal, with a melting point of 4500° F, and its alloys are uniquely suited in this respect. Under previous AVSCOM-sponsored research, the technology for precision casting (T55 engine first-stage nozzle vane) of columbium base alloys (e.g., SU-3) has been greatly improved, but further work is needed to understand the effects of operating variables on casting quality of these reactive metals. Of more immediate consequence is the casting of high temperature alloys in the directionally solidified condition to yield a product which exhibits increased thin-wall creep rupture and low cycle fatigue capability. Benefits would be realized in the production of turbine blades with the ability to operate at higher temperatures and/or with decreased cooling air requirements.

State-of-the-art, thin-wall castings do not meet high-temperature property requirements, and high-temperature mechanical properties decrease as blade thickness decreases. Of particular interest is the casting of small turbine blades with cooling passages.

Prior work has shown that some commercially available titanium alloys can be cast. Other alloys have been developed specifically for casting. Since compressor design requires high strength-to-weight and stiffness-to-weight materials for static components exposed to a temperature range of 100–800° F, certain titanium alloys have been used. Recent advances in titanium casting technology make it possible to use titanium castings for rotating components as well as static components. Manufacturing studies indicate that cost savings of up to 50% can be achieved through precision casting titanium in lieu of forging and machining centrifugal compressor components. However, further development is required to produce thin sections and complex shapes with structural integrity.

The technique of bicasting offers several advantages to the Army as a potential user of radial turbine rotors. Currently, cooled axial turbine components represent approximately 40 percent of the cost of a gas turbine engine. With the development of improved bicasting processes, the high rejection rate of present casting techniques should be reduced significantly, representing a significant life-cycle cost reduction. In addition, the radial rotor will replace two stages of the axial turbine with a single stage at reduced cost and weight.

Application. Programs aimed at developing cost effective manufacturing methods for casting high temperature alloy turbine blades must be undertaken so that benefits may be realized in the advanced technology engines under development for future airmobile systems.

A current program is aimed at developing the manufacturing technology for fabricating small, cooled, axial turbine engine blades. The primary effort is aimed at refining blade casting techniques and processes developed during the advanced development program for the UTTAS engine. A pilot production fabrication process is being established and improved to the point that the rejection rate is less

than 2 percent, while maintaining quality required for long-life engines. Special tooling and casting accessories will be developed in support of the end-item; a technical data package and manufacturing specifications will then be developed. Future work will include development of inspection techniques for cooled, axial, cast turbine blades. When work is completed, the process will have advanced from a limited fabrication operation to a full production capability.

Efforts to develop advanced titanium casting techniques will be applied to components of the auxiliary power units and the engine for the AAH and UTTAS. The centrifugal compressor impeller on the APU is presently manufactured by extensive machining of a rough forging – a costly and wasteful operation. A program to refine casting techniques and apply them to casting the impeller will result in cost savings estimated at an average of $1,000 per unit. The compressor casing on the T-700 engine is also machined from a forging at the present time. A program aimed at developing centrifugal casting techniques will result in estimated cost savings of $650 for each case.

FORGING

General. Forging consists of working metals into a desired configuration under impact or pressure loading. It allows for a refined grain structure with corresponding improvement in mechanical properties. "Precision forging" denotes a variation on the conventional process; its use often helps eliminate or minimize machining operations. In precision forging, the dimensional tolerances, surface finish, and surface metallurgical quality are equivalent to those produced by standard production machine tools. Forging is classified into such categories as closed die, open die, conventional die, precision die, and upset forging.

Technological Voids. The use of forgings in aircraft design has increased considerably as forging technology has advanced, but it still represents a small percentage of the potential application. Additional and/or continuing developmental efforts are required in the following areas:

- Isothermal forging process die capability limits and prediction of optimal combinations of temperature, pressure, and lubrication
- Isothermal roll-forging of compressor blades
- Higher strength with improved mechanical properties, especially superior fatigue and fracture toughness for titanium forgings
- Elimination of forging flash and excessive machining after forging

Technological Discussion. The isothermal forging process permits the shaping of intricate parts from difficult-to-forge materials such as titanium and high-strength steels. Die chilling is eliminated as increased plasticity of forging materials at high temperatures is maintained by keeping the dies themselves near forging temperature. Further research is needed on deformation rate, forging temperature, die pressure, and lubrication types and requirements.

Isothermal roll forging of compressor blades also holds a great deal of promise for Army aviation. Preliminary effort has indicated that reduction of the maximum section of titanium blades approaches 80 percent (Ti-6Al-4V). Such a process would yield precision, as forged contours with a fine (16 rms) finish and clean, uncontaminated surface on the processed blade, eliminating the requirement for atmospheric protection in processing and cleanup. Figure MT–2 presents an overall comparison of conventional hot forging of titanium with the isothermal roll forging process. Figure MT–3 presents this comparison for the number of reduction passes required.

Optimized thermomechanical processing effectively produces titanium forgings with superior fatigue and fracture toughness properties. Now it is necessary to produce large titanium forgings to specific processing specifications and verify mechanical

HOT FORGING	ISOTHERMAL ROLL-FORGING
MATERIAL	
SCALING IN PREHEAT	NO SCALING
METAL FLOW	
LIMITED BY DIE CHILL LIMITED BY HIGH FORGING RATE	DIE HEATED WITH STOCK SLOW FORGING RATE
DIE LIFE	
STEEL LOW THERMAL FATIGUE HIGH IMPACT FORCE DIE WASH (F_e-Ti REACTION) WEAK ABOVE 1200 °F	Mo-EXCELLENT THERMAL FATIGUE LOW FORGING PRESSURE NO REACTION WITH Ti STRENGTH RETAINED TO 2000 °F
CONTAMINATION OF FORGING	
3 TO 5 MIL DEEP	NEGLIGIBLE
SURFACE CONDITION	
>100 RMS LOW PRECISION	16 RMS HIGH PRECISION

Figure MT–2. Comparison between isothermal roll forging and conventional hot forging.

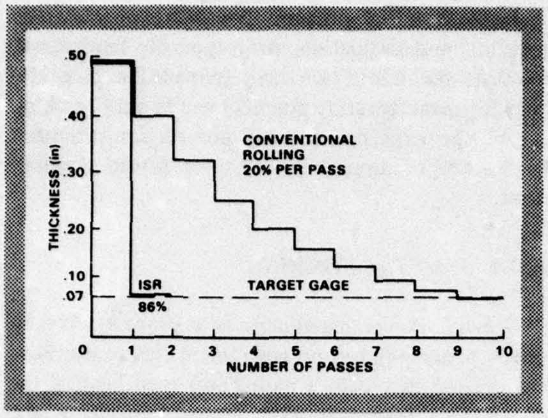


Figure MT–3. Comparison between isothermal rolling and conventional rolling; number of passes required to achieve a given reduction.

properties as a function of full-scale production forging and heat-treating variables. Both production processing specifications and base design allowable properties for components fabricated in accordance with the specifications should be formulated.

A large portion of the material in a forging is wasted in flash and machining following conventional forging. A highly developed precision forging process would allow for elimination of a majority of this flash, and proper material placement (die design) would eliminate excessive machining. The advent of this process for a particular item, such as a rotorcraft transmission component, would first require the development of new and sophisticated methods of billet preparation, die design, and billet heating. Using a selected number of components as candidates, it would be necessary to successively develop an overall process design, with (1) billet weight and material placement control, (2) determination of tooling materials, (3) detailed design and manufacturing method, and (4) optimal forging temperatures and pressures to eliminate oxidation and scaling.

Application. Full exploitation of isothermal forging of the centrifugal compressor impeller and incorporation of this forging process into impeller fabrication could reduce the associated cost of processing by a minimum of 15 percent. A feasibility forging program that will facilitate die design for the forged impeller fabrication has been completed, but further work as noted above is required. After all areas relating to the process are sufficiently understood, tooling for the impeller itself must be developed; the actual finished component will then be produced and subsequently qualified through a qualification testing program. Further research on deformation rate, forging temperature, and die pressure is required so that systems such as ASH may make use of higher-strength, forged materials possessing more desirable mechanical properties.

Isothermal roll-forging effort currently underway includes fabrication of hard tooling for blades, design and fabrication of the production machine, and subsequent work in fine grain and beta forging, followed by metallurgical and mechanical testing of the actual finished components. This technology will be available for production of compressor blades by 1980, making it available for near-term future airmobile systems.

The development of titanium forgings with superior fatigue and fracture toughness would greatly benefit all future airmobile systems, primarily in the rotor hub components.

Precision forging may be applied to spiral bevel gears on efforts as imminent as ASH. AVSCOM-sponsored research has established the manufacturing process for precision forged spiral bevel gears. Further testing of gearing produced, followed by dissemination of results to industry, should aid in implementation of the process. It is imperative that the additional effort be made now to reap the benefits of previous research.

EXTRUDING

General. The extrusion process is characterized by the forcing of metal, normally confined to a pressure chamber, through specially formed dies. In the process of cut extrusion, a heated billet is placed in a die chamber and a block and ram placed in position. The metal is then forced through the die opening. Impact extrusion, usually done with a relatively cool metal slug, can be subdivided into two major categories, forward and reverse. Forward extrusion is quite similar to cut extrusion, with metal flowing forward through an opening in the die. In reverse extrusion, the slug placed in the die is also struck with the punch, but the metal flows up and around the punch rather than forward through the die. Cut extrusion is used primarily in aviation manufacturing.

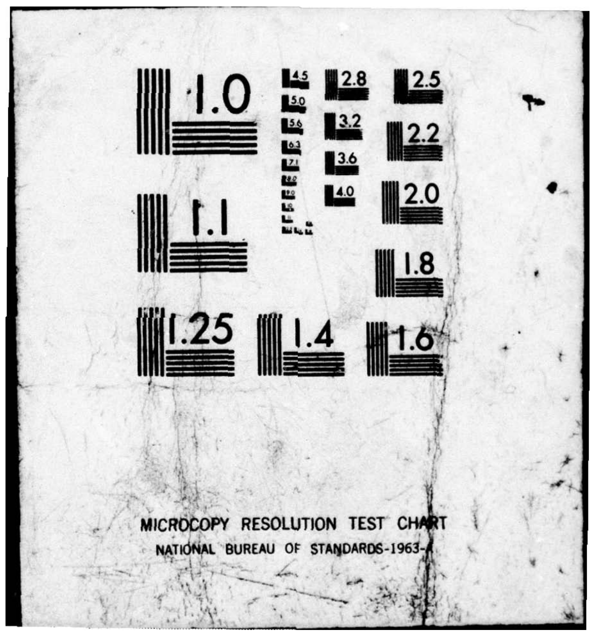
Technological Discussion. Development of the process of isothermal extrusion, wherein a nearly constant die exit temperature is maintained, will provide

AD-A035 334 ARMY AVIATION SYSTEMS COMMAND ST LOUIS MO F/G 1/3
ARMY AVIATION RDT AND E PLAN.(U)
OCT 76

UNCLASSIFIED NL

4 OF 4
AD
A035334

END
DATE
FILMED
3-77


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

an effective, highly repeatable manufacturing process for fabricating aluminum and titanium structural parts. During the process, heat is generated by friction and deformation, and heat is lost to the tooling. For a given material and reduction, extrusion speed must be varied to control the exit temperature. At present, a significant amount of process development has been completed in this area, and computer programs simulating the extrusion process by calculating heat generation, heat transport, and heat transfer for given extrusion conditions have been formulated. To assure the capability of obtaining close tolerances, forming intricate shapes, and obtaining a consistent grain structure, additional work must be performed. Further studies of exit temperature in extrusion as a function of reduction, material, ram speed, and shape of extruded product must be made. Following this, speed adjustments or variations in reduction can be determined that will assure isothermal extrusion conditions.

Applications. The isothermal extrusion process, if further development effort is applied in the near future, should be sufficiently sophisticated for availability and use by mid-FY80.

EXPLOSIVE FORMING

General. Explosive forming has been used widely for producing parts from sheet metal. Materials are generally formed with explosives in annealed condition at ambient temperature. Water is normally used as a pressure transfer medium. Acting as a ram, the water transmits pressure to the metal causing it to flow against the die contour.

Technological Discussion. Long die fabrication times and high associated costs have prevented full realization of the manufacturing potential of the explosive forming process; such a forming method is ideally suited to meet the precision sheet metal forming needs of the airframe industry. At present, limited production runs do not justify the high cost of all-metal tooling. Thus, many airframe components are composed of multipart builtup structures requiring large amounts of fabrication and assembly time. Die systems for high energy rate forming have been constructed of a variety of materials, including ice, steel, concrete, and fiberglass. Further work must be done in fabricating and evaluating such "low cost" dies, with special emphasis on components.

Application. A program consisting of materials selection and evaluation, prototype die fabrication, full-scale die fabrication, and preparation of guidelines for manufacturing practices would aid in making use of the explosive forming process for structural fabrication of aircraft planned for future development.

POWDER METAL FORMING

General. Power metallurgy is a process whereby products are made by pressing fine metal powder into the desired shape (in a mold) and then heating the compacted powder at some temperature below the melting point of the major constituent.

Technological Discussion. Trends in powder metallurgy indicate that turbine wheels for advanced engines are good candidates for application of this technology. Such wheels require exceptional tensile strength, stress-rupture strength, hot corrosion resistance, and thermal fatigue resistance. Available material does not offer an adequate combination of the required properties. The powder metallurgy approach allows for cast alloy composition, providing inherent stress-rupture strength; for wrought processing, providing tensile strength; and for limited restriction on chemical composition, providing increased hot corrosion resistance, Figures MT–4 and MT–5 illustrate some of these characteristics in comparison with conventional forging of bar stock. Further work must be done in determining the value of parameters related to the powder, forging, hot pressing, and heat treatment.

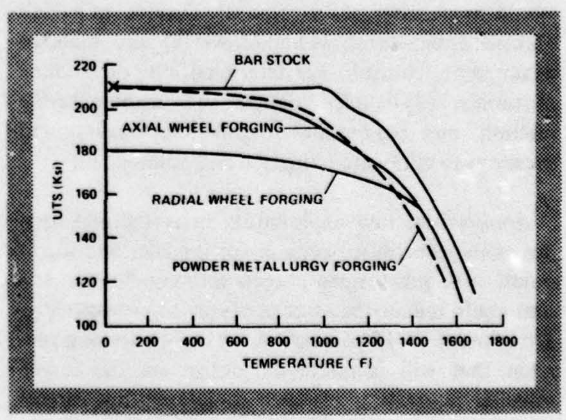


Figure MT–4. Comparison between powder metallurgy forging and bar stock forging; tensile properties.

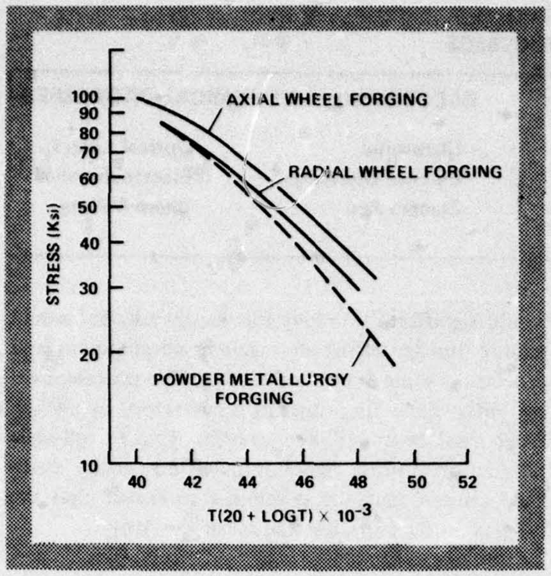


Figure MT–5. Comparison between powder metallurgy forging and bar stock forging; stress-rupture properties.

Application. A current program has demonstrated that hot isostatic pressing is a cost-effective method for fabricating turbine disks from high-hardness Rene 95 material. Powder metallurgy forging processes for the axial turbine disks are being updated and improved for production quantity utilization. The program is aimed primarily for development of the T700 engine for UTTAS and AAH.

COMPRESSION MOLDING

General. In compression molding, material is placed into a metallic mold; as the mold closes, the pressure causes the softened material to flow and conform to the shape of the mold. Compression molding is useful in forming plastics from either the powdered or solid tablet states.

Technological Discussion. A major factor in the cost of molded composite structures is the cost of tooling involved. The number of pieces produced is seldom enough to warrant the use of matching metal dies, since the cost of the dies is reflected in the cost of the part. Tooling costs can be reduced by 50 percent or more by using a low cost die material in high energy rate forming (HERF) of metal parts. This die system can be prepared quicker than conventional matched metal molds; the dies themselves would possess a hard nickel surface backed up by a reinforced concrete-like material. The nature of such dies allows for the introduction of heating and cooling coils near their mating surfaces; this feature permits uniform heating and cooling of the die face and eliminates the need to heat the whole die, a costly and time consuming operation.

A solution to the problem of low stiffness in transmission gearbox housings can be realized by compression molding these housings. In this case, high modulus, unidirectional, continuous filament graphite epoxy would be used. A determination of manufacturing procedures and techniques, coupled with optimization of a gearbox housing design and the fabrication of production-tooling, dies, and molds, must be completed prior to fabrication of prototype housing. Simulated static and dynamic test results of prototype housings must be compared to existing magnesium housing test results to establish acceptability.

Application. A recent program utilizing low-cost, integrally treated dies for fabricating Kevlar fairings has established the feasibility and low-cost benefits of this process and demonstrated its applicability to systems now under development, such as UTTAS and AAH.

Development of filament graphite-epoxy compression molding techniques could be completed in time for systems entering engineering development by FY80.

MACHINING PROCESSES

GENERAL

Processes classified as machining operations are included in table MT–D.

Although chip removal processes are widely used throughout the aircraft industry primarily because the base material properties normally remain unchanged, such processes are extremely wasteful. Consequently, few efforts aimed at refining chip removal processes are being undertaken. Rather, efforts to do away with extensive machining are of more interest to Army aviation. Where a unique application exists or where no other type of process is acceptable, machining processes are undergoing further development. Such is the case with ultrasonic machining, electric discharge machining (EDM) and electrochemical machining (ECM).

TABLE MT–D
MACHINING PROCESSES

MECHANICAL CHIP REMOVAL PROCESSES			ELECTRONIC OR CHEMICAL PROCESSES	
Turning	Planing	Shaping	Ultrasonic	Optical Lasers
Drilling	Boring	Reaming	Electric Discharge	Electrochemical
Sawing	Broaching	Milling	Electro Arc	Chem-Milling
Grinding	Hobbing	Routing		

ULTRASONIC MACHINING

General. In ultrasonic machining, sonic energy is applied to a tool performing work on a block of raw material. Many ultrasonic machining operations have advanced little beyond the experimental stage; necessary baseline data is in most cases minimal if available at all. Figure MT–6 presents a brief review of the current status of some processes. There are several potential areas for ultrasonic energy application in Army aircraft manufacturing, as determined from a recent AVSCOM study. Some of the processes requiring additional development are discussed below.

Technological Discussion. Ultrasonically assisted turning on outside diameters offers a solution to the problem of hand-polishing to remove tool marks that might contribute to structural failures. Such a process would significantly reduce this handwork, but would require further effort in machine development and processing some items for testing. The process, as it currently exists, is primarily a laboratory operation. Work must be undertaken to bring it up to full-scale production process. Baseline data and quality assurance criteria must be developed to ensure that the process produces usable results for the Army.

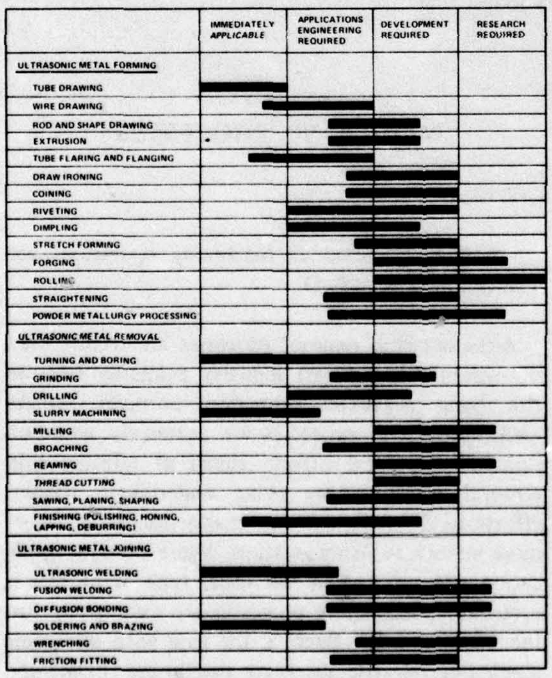


Figure MT–6. Ultrasonic processes.

Rotary ultrasonic machining, wherein both rotational and axial vibration are imparted to a tool, has proven effective on processing such material as high-alumina ceramics, technical ceramics, ferrites, porcelain, glass, boron-tungsten laminates, and beryllium. Operations performed in these materials, using the rotary ultrasonic concept, include drilling, milling, grinding, threading, and specialized lathe operations. Figure MT-7 presents a typical comparison between ultrasonic and nonultrasonic drilling (the work piece is 1/15-inch titanium). However, while many superhard materials can be effectively machined with the rotary ultrasonic principle, others cannot be. Machining of boron carbide remains largely a laboratory phenomenon, primarily due to the fact that its hardness approaches that of the diamond tool itself. Much work must be done in examining the bonding agent that secures a diamond tool to its holder, since the agent currently holds the diamond so tightly that

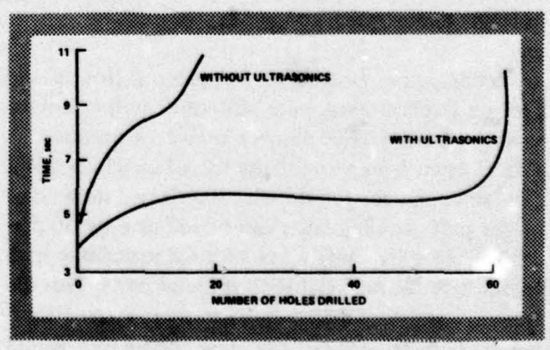


Figure MT–7. Comparison between ultrasonic and conventional drilling.

worn diamond is not expelled from the work area; cutting edges thus become cluttered and wear down. In addition, effort must be expended in the drilling of extremely small holes (0.04-inch diam) before such an operation becomes practical for full-scale production.

Application. A current program aimed at scaling up the ultrasonically assisted turning operation will allow application of this process to the full-scale production of systems as imminent as UTTAS and AAH.

Work must be undertaken to establish manufacturing parameters for other ultrasonic machining processes for application to developmental systems, such as ASH.

ELECTRICAL DISCHARGE MACHINING

General. In electrical discharge machining metal is removed by rapid spark discharge between a negative electrode, the tool, and a positive conductive workpiece, separated by approximately 0.001-in. of dielectric fluid. The workpiece material is cut away by the spark discharge, and dielectric coolant washes away the particles of eroded metal. The EDM process was developed for machining carbides, hard nonferrous alloys, and other hard-to-machine materials.

Technological Discussion. Present state-of-the-art technology for ceramic machining does not permit economical processing of intricate, large shapes. The current method entails "hogging" the pieces from a single billet by conventional machining; such an operation is quite costly and time consuming on a ceramic as hard as silicon carbide. Use of EDM would greatly reduce machining time and in addition would reduce tooling costs, as the diamond tooling normally required in the conventional process would not be required. Also, EDM is an extremely attractive method for machining complex shapes such as turbine components. Further effort is required in investigating the effect of varying process parameters (e.g., tool material, size, and shape; feed rate; dielectric fluid) on properties of the as-machined component. Comparisons between its conventional counterpart, based on an evaluation of the physical properties and parameters of each, must be made. Surface characterization by optical and scanning electron microscopic techniques must be conducted and attempts made to establish a correlation between surface finish and strength properties.

Application. The use of EDM for machining ceramics should be ready for application to aircraft components in the 1980s.

ELECTROCHEMICAL MACHINING

General. In electrochemical machining the raw material to be machined functions as an anode while the tool functions as a cathode. A current is passed through a flowing film of conductive solution separating workpiece from tool. In effect, ECM is a deplating operation wherein metal is removed from the workpiece by electrochemical decomposition. Typical applications of ECM to aircraft include use in making turbine and compressor wheel blades, drilling engine cooling holes, face turning of discs, and performing various other operations on high-temperature alloy forgings and high-strength, high-hardness materials.

Technological Discussions. Current conventional machining methods for centrifugal/radial compressor wheels is time consuming, necessitates multiple setups, and consumes tooling at a rapid rate. Newer superalloys and titanium alloys developed for their high strength capabilities are receiving increased attention for use as compressor wheel materials. Unfortunately, the improved materials are not efficiently machined by conventional techniques. Further required effort includes the establishment of initial tooling and ECM process parameters, fabrication of tooling and machining of test items from conventional materials, subsequent machining of test pieces from titanium alloy, and testing, inspection, and comparison of these items.

Application. Further development of the ECM process could benefit systems entering engineering development after 1980.

JOINING PROCESSES

GENERAL

The joining processes can be categorized into three main areas:

- Mechanical Joining.
- Metallurgical Joining.
- Chemical Joining.

Mechanical joining processes will not be addressed in this section, since they are actually an "assembly"

operation rather than a process, in that the means for fastening together a number of parts is totally mechanical.

METALLURGICAL JOINING

General. Several metallurgical joining processes are of interest to the Army; among these are welding, soldering, brazing, and solid-state bonding. Of primary future interest to Army aviation are processes of welding and solid-state bonding.

Technological Discussion. The present method of manufacturing a titanium rotor blade spar consists of extruding the part and fully machining it all over. The finished machined spar weighs only about 10 percent of the starting extrusion. Because the cost of titanium is high and this process involves a considerable amount of scrap and machining, this method is too costly for production incorporation of titanium spars. A titanium main rotor blade spar produced by cold brake forming a Ti–6Al–4V sheet and welding or diffusion-bonding the seam would bring about estimated cost savings of at least $2600 per spar. The seam on such a spar requires a long, narrow, smooth configuration free of joint mismatch, undercut and porosity. Present joining systems are marginal in capability and must be scaled up to make required high-quality bonds on a routine production basis.

The increased performance characteristics being specified for advanced helicopter designs will require a proportionate increase in the size of many of the major helicopter components. Of particular significance are those components where large size, high strength, and minimum weight are prime considerations (e.g., motor mounting, landing structures, hold-down tabs, spars for blades, and panel stiffeners). Current press capacities would be exceeded to forge many of the new components needed for advanced helicopters, and the limited use would not justify the cost of building larger presses. Effort may be directed toward providing specifications and description of manufacture for prototype assemblies that will be made from combining smaller structural elements to form larger components through the use of precision joining techniques such as solid-state bonding and diffusion bonding. Delineation of the pertinent manufacturing process parameters for conventional hub assemblies and examination of requirements for conversion to welded assemblies must be accomplished.

Application. As titanium tubes for certain blade spar configurations will require joints in tapered wall thickness and/or varying spar diameters which cannot be adequately accommodated by present day fabricating systems, it is necessary to scale up equipment for tube joining. Results of this effort would be immediately applicable to UTTAS.

The joining of high-strength-to-weight ratio materials such as titanium alloys has been proven to be a technically feasible fabrication process, but a need exists to develop the manufacturing method and application. Results of such effort would be particularly applicable to systems fulfilling mobility mission requirements.

CHEMICAL JOINING

General. Chemical joining, as previously noted, is defined as the holding together of two or more parts by the application of a chemical agent between the parts that, by means of a chemical interaction, creates a bond. Adhesives are substances normally used to hold such parts together; types of adhesives include natural, thermoplastic, thermosetting, and elastomeric. Of primary interest here are thermosetting adhesives. The joints formed are stronger than the other adhesive types and heat resistance is exceptional (up to 500° F).

Technological Discussion. In many manufactured components, the effect of bond line variations on service capabilities is virtually unknown. As a consequence, manufacturing tolerances on adhesive bond line are often determined on the basis of the most refined production technique. It appears that establishing accurate tolerance criteria would lead to a possible choice of a more economical manufacturing technology. Tolerance requirements must be established for typical strips, sheets, and cylindrical configurations using commercial nylon-epoxide adhesives as well as advanced high-temperature systems. On the basis of unusual assembly procedures, a series of joint tests must be performed wherein adhesive line geometry will be systematically varied with the range of ordinary dimensional control. Subsequently, fatigue experiments should be conducted for temperatures varying from −67° to 350° F.

Application. Data would then be available on tolerance requirements for important classes of structural materials and adhesives. Application of results would be primarily limited to airframe attachments and joints on near-term future airmobile systems.

SURFACE FINISHING PROCESSES

GENERAL

Table MT–E lists surface-finishing processes. Of particular interest to developers of manufacturing processes are inorganic coatings, grinding, and electroplating.

TABLE MT–E
SURFACE-FINISHING PROCESSES

Polishing	Metal Spraying
Abrasive Belt Grinding	Superfinishing
Barrel Tumbling	Inorganic Coatings
Honing	Anodizing
Lapping	Parkerizing

INORGANIC COATINGS

General. Many inorganic coatings have been developed for a wide variety of uses, but present coatings are insufficient to solve many of the problems associated with Army rotorcraft systems. To this end, new coating materials, methods, and processes are being developed. The four basic methods used to impart coatings to material are:

- Metallurgical
- Electrochemical
- Chemical
- Mechanical

Technological Discussion. Because of their high strength-to-weight ratio, titanium alloys have been considered for use in transmission gears, but such applications depend on the development of compatible alloy/coating systems to overcome wear and galling problems. Several promising coatings for titanium alloys have been developed on a laboratory scale but have not been applied in a production environment to gear profiles and thick-section parts with extremely close tolerances. Previous R&D includes investigation of the effects of temperature on the coating structure and thickness, and an examination of coating adhesion, wear resistance, and mechanical properties of the base materials. Diffusion treatments for electroless nickel coatings plus chromium, at temperatures in the 850–1350° F range, have resulted in marked improvement in adhesion and wear resistance with little or no degradation in mechanical properties. Wear-testing under identical conditions indicates that the diffusion-bonded coating on titanium is superior to case-hardened steel. Coating processes must be scaled up and modified to accommodate large gears and roller test specimens.

Titanium alloys cannot withstand the erosive, corrosive environment to which they would be exposed in the compressor section of gas turbine engines. Protective coatings of titanium diboride and titanium carbonitride have been developed and evaluated in the laboratory. Manufacturing methods must be further developed to minimize coating variations over close tolerance component profiles. The extent of these variations and the effect of the coating on the mechanical properties of the component material must be determined. Production techniques for coating engine components are still to be developed and coated components tested.

Application. Programs to establish manufacturing methods for applying coatings must be undertaken in order for titanium to become acceptable for specialized application in future airmobile systems.

ELECTROPLATING

General. The process of electroplating consists of passing an electric current from an anode to a cathode (this being the object on which metal is deposited) through a suitable electrolytic solution in the presence of a catalyst. Electroplated coatings provide wear resistance, corrosion resistance, hardness, and reflectance. The process is relatively inexpensive and can be applied to many different shapes and sizes, although it is somewhat difficult to achieve plating on contours, grooves, fins, ribs, recesses, and angled edges.

Technological Discussion. Much effort is being expended in investigating various coatings for helicopter transmission gears. AVSCOM-sponsored investigation has indicated that honing of gears can increase resistance to scuffing by 25 percent (at 10 rms) over current gears using AISI-9310 material. However, it has been determined that electroplated coating of current gearing can provide even greater resistance to scuffing; silver plating has increased scuff resistance by 75 percent over current transmission gears. Preliminary tests have shown that the surface finish of the gear had also increased from the normal 12 rms to 5 rms. In addition, it has been shown that VASCO–X2 material provides increased load-carrying capability and scuff resistance.

Application. Further work remains to be done in actually implementing the process of silver electroplating. Quality assurance provisions and a technical data package must be written; however, the basic manufacturing concept has been examined and recently proven sound. Benefits of this effort will accrue to that generation of Army aircraft now under development, including UTTAS and AAH.

GRINDING

General. In machine shop practice, grinding refers to the removal of metal by means of a rotating abrasive wheel. Very little pressure is normally required, and work can be finished to very accurate dimensions within a short time.

Technological Discussion. The hydrostatic grinding process, wherein a conventional gear grinder is equipped with hydrostatic air spindle and hydrostatic ways for improved grinding capability, can yield spur and helical gears having approximately 2.2 times the load capacity of conventionally ground gears of 10 rms surface finish. Surface finishes of 1.0 rms have been obtained with total topographic variations across the gear tooth of less than 0.000025 inch and local variations of less than 0.000005 inch. The hydrostatic grinding process will be applied to other types of gearing in the future.

Application. A final report on the work has been completed; the process of hydrostatic grinding for aircraft-quality gearing appears ready for mass production, although additional checkout and flight testing of associated gearing must be accomplished.

COMPUTER-AIDED MANUFACTURING

GENERAL

Computer-aided manufacturing (CAM) is an ever-widening field in terms of manufacturing operations capable of being performed in conjunction with a computer. Although operations currently performed by CAM could be classified under their more conventional headings (e.g., milling, forging) it is felt that the area of computer-assisted manufacturing operations deserves special attention as an entity in itself.

HELICOPTER GEARING

A promising application of CAM lies in the design and production of helicopter gearing. Conventional gears are overdesigned to allow for deficiencies in tool design and fabrication. If gears and gear tooling were designed simultaneously using the aid of a graphic interactive device such as the IBM 2250 CRT, a large amount of this overdesign would be eliminated and a more accurate tooth profile configuration would result. In addition, a numerical control tape could be generated by the computer after the gears and tooling were designed. By running the tape through a suitable postprocessor, a series of instructions to a machine tool would be generated, again in tape format. The tooling can then be generated followed by use of that tooling in the actual gear cutting process. Thus, much of the conventional gear design and manufacturing process could be automated. It is estimated that overall prototype production leadtime would be reduced from 18 months to approximately 8 months. It is also anticipated that the optimized gear design may provide an increase of 25 percent in gear durability, thus significantly decreasing acquisition and support costs. Such effort would support systems entering engineering development after 1980.

COMPOSITE STRUCTURE

The use of filament winding in fabricating advanced composite structures should also be increased within the next 20 years. AVSCOM-sponsored effort is developing improved techniques and equipment to automate the fabrication of Tetra-Core, a fiber-reinforced composite core material. The primary applications of Tetra-Core lie in the replacement of existing aluminum honeycomb structures and the use of actual structural elements. Work still to be performed includes investigation of both filament winding and complex weaving techniques to determine the optimum technique to fabricate Tetra-Core efficiently. Following this, the design and development of equipment, tooling, fixtures, and adapters required to prove out the fabrication approach must be conducted. Fabrication of prototype production equipment capable of producing Tetra-Core with combined/controlled variables of core thickness, width, length, cell dimension, and fiber/matrix ratio must then be accomplished. The process itself will be sufficiently developed for use in production by 1979.

A six-axis, tape layup machine is being developed under AVSCOM sponsorship for use in the automated manufacture and monofilament fiber composite structures. Currently, the benefits available from use of composite materials in helicopter rotor blades cannot be realized on mass production basis; composite

blades are hand-wrapped, thus requiring large amounts of time and money. The tape layup machine under development will provide an automated method for fabricating these complexly contoured blades. Special features of the equipment to be developed include layup capabilities at 100–300 inches per minute, capability for closely controlled cross-sectional area, and ability to maintain tight tolerances on tape alignment. The current effort is in the machine fabrication phase; design and planning have been completed. Results of the effort should be completed in time for use on such systems as ASH.

COMPUTER-AIDED DESIGN/MANUFACTURING

AVSCOM is sponsoring work to establish a method for computer-aided design (CAD) and computer-aided manufacturing of extrusions. The use of CAD is primarily in the preforming and finishing dies, while CAM will be applied mainly to the manufacture of dies. The computerized method of actually designing the process and the dies to be used in that process is being developed for use in an interactive mode. A cathode ray tube terminal, connected to a CDC 6400 computer, is being used in designing the outline and cross section of the extrusion dies. Further work would include the selection of candidate items to be extruded and the use of data developed in the actual extrusion process. Subsequently, design and process specifications would have to be formulated and finalized. The process could be ready for use in manufacturing Army aircraft components by 1980.

[redacted]

INTRODUCTION

GENERAL.

It is readily apparent from the foregoing technological discussions that an attempt to categorize and prioritize the technological efforts associated with manufacturing technology would be a monumental task and would actually not be appropriate for this RDT&E Plan.

However, it is appropriate to divide MT efforts into the categories listed below and to assess the MT efforts that should be applied to each of the categories:

- Airframe
- Turbine Engine
- Drive System
- Rotor System
- Aircraft Equipment

Figure MT–8 presents a ranking of the relative anticipated effort for each of the five categories.

PRIORITY	CATEGORY	ANTICIPATED PERCENTAGE OF TOTAL MT EFFORT
1	TURBINE ENGINE	27%
2	AIRFRAME	23%
3	ROTOR SYSTEM	20%
4	DRIVE SYSTEM	17%
5	AIRCRAFT EQUIPMENT	13%

Figure MT–8. Relative efforts anticipated by MT category.

TECHNOLOGICAL RATIONALE

Turbine Engine. The development of technology to manufacture existing or anticipated high-performance engines and associated components to overcome existing problems is required. Expected operational characteristics aimed toward more efficient turbine engines are higher operating temperatures and increased ratio of power/weight. Particular emphasis will therefore be evident in the MT development of components utilizing ceramics such as silicon carbide or superalloys with high-temperature fatigue life, for example.

Airframe. The manufacturing technology required to produce the airframe (aft or fuselage) and secondary structures (such as skins and stringers) must be developed. Considerable effort is anticipated in this area due primarily to emphasis on increasing the strength/weight ratio. As a result, particular emphasis is being placed on developing MT for structures made from titanium, composites, and other high-strength/weight materials.

Rotor System. Technology to manufacture metallic and nonmetallic rotor items and associated components such as blades, hubs, or spars must be developed in order to increase performance and reliability.

Again, particular emphasis is placed on such high-strength/weight materials as titanium and the composites. As a result, considerable additional effort is necessary to develop the MT processes for rotor items made of these advanced materials.

Drive System. Requirements call for the development of manufacturing methods for moving and nonmoving parts and associated components such as shafts, gears, bearings, and transmission housings in order to increase reliability and decrease costs. Primary problems anticipated in the drive system are difficulty and cost in the manufacture of gears and performance problems with transmission housings and gears.

Aircraft Equipment. Considerably less effort is anticipated in the area of MT development for helicopter equipment. The primary reason is that requirements in this area are usually for items that have a low manufacturing development cost, such as cargo slings. Components of critical importance, such as transparent and ceramic armor, are included in this category, however.

DESCRIPTION OF PROJECTS

INTRODUCTION

The primary objective of the AVSCOM Manufacturing Methods and Technology Program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in the production of Army Aviation materiel. The overall goal of the MMT program is to assure that the Army is able to produce helicopters with maximum performance and reliability at a reasonable cost.

Several of the FY77 efforts in MMT are directed specifically at the General Electric T700 engine to be used on both the UTTAS and the AAH. These projects will be implemented immediately upon their completion and offer a substantial return-on-investment.

IMPROVED MANUFACTURING OF BLISK AND IMPELLER TURBINE ENGINE COMPRESSOR COMPONENTS

Project 1777103 is an effort to develop the manufacturing methods and processing specifications for the cost effective production of integrally fabricated blades and disks (blisks) for the T700 engine. The design for the T700 engine requires that blades and disks in the compressor section be integrally fabricated. General Electric (GE) has identified a multi-spindle machining approach because it offers a substantial cost reduction and low technical risk. The plan is to machine the blisks and impeller on numerical controlled, multi-spindle milling machines of the forged pancake for both the disk and blade portion of the blisk and impeller.

Current fabrication methods used to produce prototype integrally fabricated blisks for the advanced turbine engine compressor stage involve single spindle machining out of a forged pancake for both the disk and blade portions. The finishing is currently being performed by hand, which is very time consuming. The proposed multi-spindle machining process and mechanical finishing process can reduce the procurement costs of the T700 by $7861 per engine.

IMPROVED MANUFACTURING TECHNIQUES FOR INFRARED SUPPRESSION AIRCRAFT COMPONENTS

Project 1777114 will establish manufacturing methods and techniques for cost effective production of infrared (IR) suppression systems for turbine engines. Due to the new Army requirements for IR suppressors to provide protection against such devices as heat-seeking missiles, industry has developed a variety of new IR suppression devices. These newly developed IR suppression devices require manufacturing methods and technology development, such as low and high temperature brazing techniques for cooling fins, forming finned ducts and elbows, manufacturing and bonding of duct metal insulation blankets, forming of brazed structures to complex geometric shapes, and other manufacturing techniques for production of IR suppression systems. Various laboratory tooling and fabrication techniques will be investigated to determine the optimum manufacturing methods.

TURBINE ENGINE MULTIPLANE BALANCING (CAM RELATED)

Project 1777111 is a one-year effort to establish a process for multiplane balancing of the gas generator and power turbine rotors in the production line of the T700 engine. With the trend to lighter-weight, higher-temperature, high-speed engines, supercritical rotor operation has become an accepted design

practice (the rotor operates above a bending critical speed). Present procedures utilize two-plane balancing and require that the shafts be manufactured to very close tolerances on straightness and concentricity. Over the past five years NASA-Lewis Research Center, in conjunction with Mechanical Technology, Inc., has developed multiplane balancing techniques utilizing integrated computer programs for response-balancing calculations. Applicable R&D has been accomplished under NASA contracts NAS3-10926, -14420, -18520, and -19408. This project will utilize the NASA/MTI technology and will be applicable to the T700 engine and indirectly to the T53 and T55 engines. Multiplane balancing will reduce manufacturing costs by allowing relaxed tolerances of concentricity and straightness.

T700 TURBINE ENGINE NOZZLE MANUFACTURING PROCESS

Project 1777104 will develop processing techniques for turbine engine nozzle manufacturing. Grinding techniques will be optimized for machining nozzles made from cobalt and nickel alloys. This work will be performed mainly by an industrial contractor (GE) engaged in the development of the T700 engine. A portion of the testing and evaluation phase will be carried out in-house at AMMRC.

Optimized nozzle grinding will result in closer dimensional control thereby improving engine performance and reducing hardware reject losses. Further, considerable time is saved in a more repeatable and less expensive nozzle area measurement technique.

T700 ENGINE NOZZLE IN-PROCESS INSPECTION

Project 1777144 will develop an in-process inspection technique for turbine nozzles. Automatic electrical measurement of nozzle areas for air flow and infrared scanning for flow blockages will be developed along with holding fixtures to group nozzle segments as a full assembly. This will speed the necessary area measurement and flow control checks, thereby reducing operational cost. The work will be performed mainly by an industrial contractor (GE) engaged in the development of the T700 engine.

ULTRASONICALLY ASSISTED FORMING OF NOSE CAPS FOR ROTOR BLADES

Project 1777052 is an MM&T effort to develop the production techniques for cold forming erosion resistant nose caps for helicopter rotor blades. Currently titanium nose caps for the CH-47 Modernization, UTTAS, and CH-46D fiberglass rotor blades and stainless steel nose caps for the AAH are being hot formed. The hot forming process requires long processing times, high-cost tooling and equipment, expensive chemical etching. Based on results of prior IR&D efforts and demonstrated effects of ultrasonics on forming of other materials, ultrasonic energy will solve the problems associated with the cold forming, process, such as force required, springback, and cracking.

This project is a follow-on effort for scaling up the FY75 feasibility study which will be completed in May 1976. Ultrasonically assisted forming will support the Army's Cost Reduction Program by reducing processing costs and costs of expensive tooling and equipment.

MANUFACTURING TECHNIQUES FOR TRANSMISSION SHAFT SEALS

Project 1777108 will provide the manufacturing technology for the integral molding of a hybrid elastomeric segmented ring seal. The process will eliminate the critical machining of the housing and segmented ring currently required. This type of seal has been developed at NASA-Lewis Research Center based on previous work done on a circumferential shaft riding seal with a metal housing. Additionally, this seal design has successfully completed extensive in-house rig testing and over 460 hours of flight test in a UH-1 at Fort Rucker. This type of seal should extend the life of the UH-1 input seal from the current 300 to 1500 hours (overhaul goal time for the transmission). The project is applicable to all advanced higher speed transmissions such as AAH and 214 series helicopters. This project will provide manufacturing technology to produce a low-cost, high-speed seal at about one-third the cost of conventional high-speed seals.

A seal in which the segments are an integral part of the molding process, such that the elastomeric material completely fills the imperfections and leakage path of the segments, will give higher speed capability and longer life than presently used elastomeric lip seals. This effort will establish a method for molding the segments as an integral part of the elastomeric mold and eliminate the critical machining of the housing and segmented ring. This work will be performed mainly by an industrial contractor with expertise in molding of elastomeric type seals. The

molded seals will be evaluated by the same or a different contractor under conditions seen in the UH-1 transmission and also at higher shaft speed conditions to simulate advanced transmission design.

PRECISION CAST TITANIUM COMPRESSOR CASING

Project 1777046 is an effort to develop and demonstrate titanium precision casting methods as a suitable means of manufacturing compressor casings for the T700 engine instead of titanium forging as is currently used.

It is planned to precision cast the exterior to finished dimensions, thus eliminating the necessity for several costly contour milling operations presently required. Manufacturing costs will be saved both by the elimination of the contour machining operations and by the difference in cost between forgings and castings. In addition, better utilization of raw material, ingot, will result.

The casting technology developed will be available for application to other future engines where design and cost factors favor titanium precision castings for primary structural components.

CAST COMPRESSOR COMPONENTS

Project 1777070 will establish a manufacturing process for casting components from alloys with suitable properties such as precipitation hardened stainless steels or titanium alloys which will extend the application of cast alloys into the dynamic application area resulting in a substantial cost reduction. The results of this project will be directly applicable to the auxiliary power unit on the CH-47, AAH, and UTTAS, and will advance technology for application to such future engines as LTS-101.

COMPOSITE IMPROVED MAIN ROTOR BLADES (AH-1 HELICOPTER)

Project 1777112 will utilize the R&D efforts under project 1F264212D639 Task 03 during FY75, FY76, FY77 totaling $8.40M in designing the composite main rotor blade, selection of materials and aerodynamic shape producing the best lift. The Deputy Secretary of Defense memorandum for the Secretary of the Army, 7 Mar 74, subject: Product Improvement Program (PIP) for AH-1Q (TOW) Attack Helicopter and Assistant Secretary of the Army memorandum for the Deputy Director of Defense Research and Engineering, 13 Aug 74, subject: AH-1Q Composite Rotor Blade Program, have directed the AH-1Q Improved Main Rotor Blade Program. These documents have stressed the urgency of the program and accelerated required actions. In-house and contract R&D efforts on composite rotor blades have resulted in contract number DAAJ01-75-G-0806 with Kaman Aerospace Corporation.

This contract will provide the government with a technical data package from which further requirements could be competitively procured as well as hard tooling on which the items could be fabricated. However, manufacturing problems which are encountered during large scale production utilizing this tooling will not be addressed due to the relatively small number of blades required for R&D. This PEM project for FY77 is to apply the technology developed during prior in-house and contractor efforts to the mass production of filament-wound rotor blades. Government facilities would be inadequate for large-scale production. AVSCOM will be responsible for product evaluation and in-service testing.

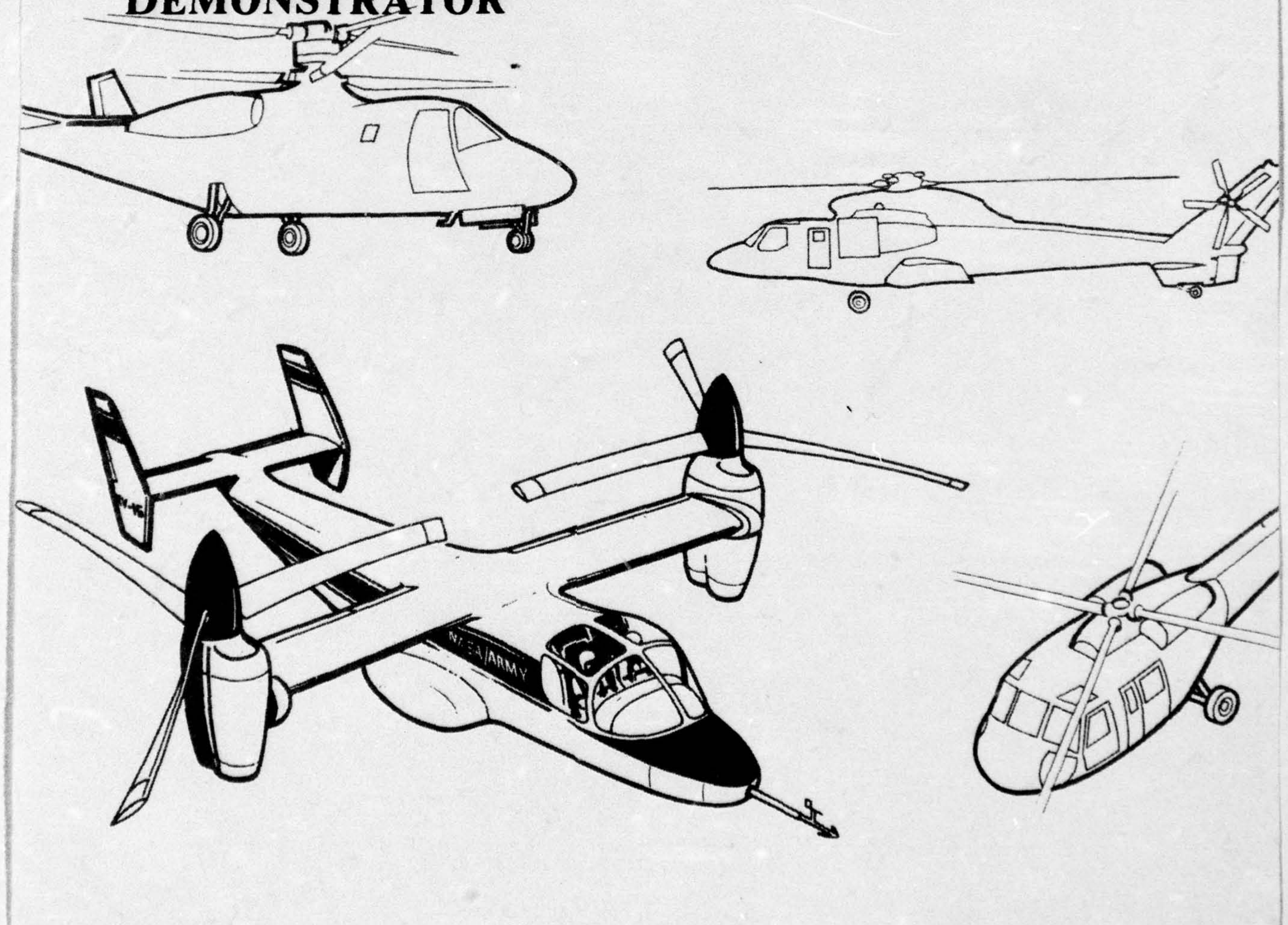
INTRODUCTION

TILT ROTOR AIR VEHICLE

ROTOR SYSTEM RESEARCH AIRCRAFT

ADVANCING BLADE CONCEPT

ADVANCED STRUCTURES TECHNOLOGY DEMONSTRATOR



INTRODUCTION

Progress in improving performance of Army helicopters and other VTOL concepts will be paced by the technological advances in propulsion systems, drive systems, rotors, flight controls, and structural materials. Emphasis on performance must be tempered by considerations of maintainability, reliability, and survivability to achieve acceptable operational characteristics.

Although the specific mission requirements have not been defined for various aircraft concepts, it is possible to identify promising concepts and the research efforts required to develop the technology base needed to support these concepts.

To obtain the increased performance and utility of the aerial vehicles introduced into the Army between now and 2000 depends directly upon the establishment of a broad technological base of knowledge, experience, and demonstrated concepts.

The programs described in this section were formulated on the basis that advances in state-of-the-art technology can only be made if technology is validated by component or system demonstration in actual or simulated flight conditions. Fundamental technology will be validated in this manner to provide criteria for incorporation into design of future Army vehicles.

TILT ROTOR AIR VEHICLE

GENERAL

A major problem addressed in the discussions of many of the technologies in this plan is the high dynamic loads experienced by the helicopter rotor during cruise operation. These high dynamic loads not only restrict the performance capability of the helicopter but, more importantly, generate the vibrations and noise that result in the fatiguing of structures, components and aircrew, reduced availability, and increased maintenance and support costs. Moreover, in addition to the VTOL capability requirement, several of the Army airmobility missions identified in this document would benefit greatly from the increased productivity that a higher cruise speed could provide. The tilt rotor, one of the candidate aircraft concepts considered for these roles, offers promise of significant improvement in these areas while providing the desirable VTOL characteristics of the low-disc-loading rotary wing aircraft. Therefore, over the past 8 years, the Army has actively supported a program to develop the technology required to enable the implementation of this type of air vehicle. Knowledge in all key disciplines has now advanced (through full-scale component experimental investigations) to the point where the flight demonstration of the integration of all technologies is warranted. The program to accomplish this is being conducted jointly with the National Aeronautics and Space Administration. This activity, the XV-15 Tilt Rotor Research Aircraft Project, and follow-on tilt rotor air vehicle programs are discussed in this section.

CONCEPT CHARACTERISTICS

The principal flight modes of the tilt-rotor aircraft (figure AT–1) are hover or helicopter, transition or tilt rotor, and cruise or airplane.

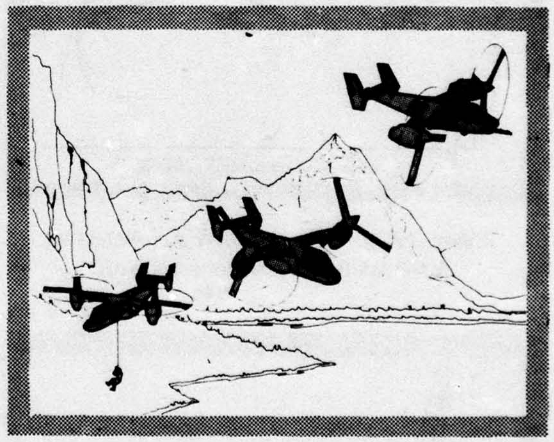


Figure AT–1. Tilt rotor principal flight modes.

The key potential advantage of the tilt rotor concept is that it combines the efficient static lift (hover) capability associated with the low disc loading helicopter with the efficient cruise performance and low vibration of a fixed wing turboprop aircraft with cruising speeds on the order of 300 knots. Eliminating the requirement to operate the rotor in the edgewise flight mode for high speed (cruise) permits the blades to be tailored with a high spanwise twist and camber distribution that significantly reduces induced and profile losses, therefore

improving hover efficiency. Figure AT–2 illustrates the effects of the major rotor characteristics on hover and cruise mode performance. The impact of the improved hover efficiency (Figure of Merit) is illustrated in figure AT–3, where, for equivalent disc loadings (i.e., downwash velocities), the tilt rotor will yield a measurable increase in thrust (gross weight) per horsepower (or conversely a reduction in horsepower required to produce a specific thrust level).

As in all two-point design situations, the tilt rotor blade geometry represents a tradeoff between the hover and cruise requirements. However, by reducing the rotor tip speed (RPM) to about 80% of the hover value after conversion to the airplane mode the extent of the compromise is minimized due to the increase in blade loading. Therefore, cruise propulsive efficiency is increased, while engine performance and transmission/drive system torques are maintained at desirable levels. The moderate tip speeds and non-oscillatory blade loadings of the tilt rotor will also result in a reduced acoustic signature compared to other VTOL concepts.

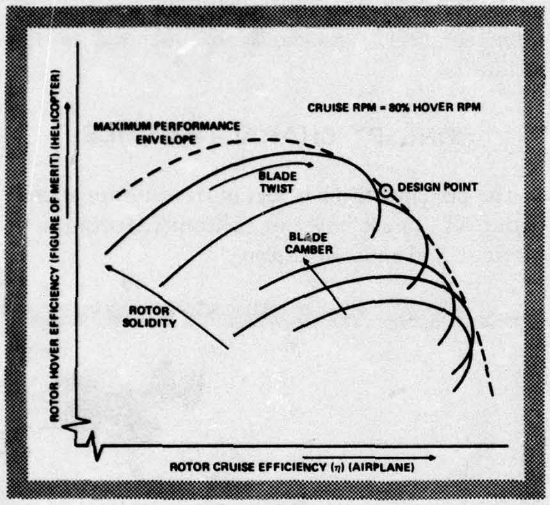


Figure AT–2. Effect of rotor parameters on hover/cruise performance trade-off.

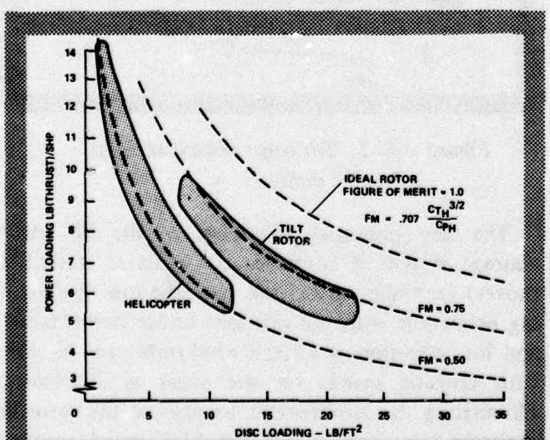


Figure AT–3. Disc loading effect on rotor hover efficiency.

A significant product of the combination of high efficiency of the tilt rotor in both the hover and cruise flight modes is fuel conservation. For example, the higher rotor performance results in a requirement for smaller engines to perform a typical hover/cruise/hover transport mission. As an additional bonus for mid-to-long-range applications, the higher cruise mode speeds (at lower power levels) will also result in an increase in productivity (payload X delivery speed/empty weight (cost factor)). High endurance capability at moderate airspeeds due to a reduction in power required (see figure AT–4) is another benefit of the fuel conservative tilt rotor.

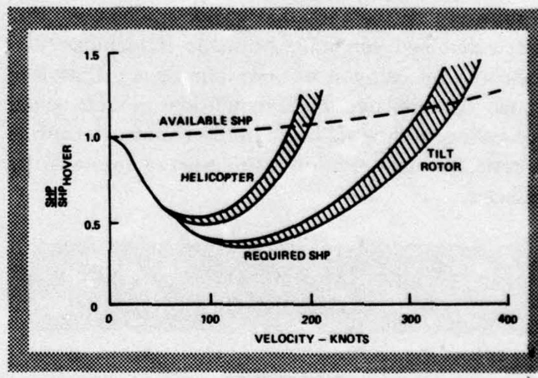


Figure AT–4. Power required comparison.

The relatively short duration of forward flight in the helicopter mode for most applications results in a favorable fatigue environment for both the tilt rotor vehicle and the crew, as compared to the helicopter (see figure AT–5). The use of the wing to sustain lift in cruise flight and the associated reduction in the dynamic loadings on the rotors will also contribute to a reduction of crew fatigue by improving flying qualities and lowering cabin vibration levels. A further result, and perhaps the most significant, is the expected increase in reliability and reduced maintenance required.

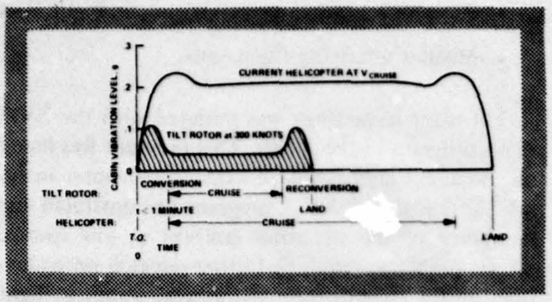


Figure AT–5. Vibration environment.

Additional benefits of the use of low disc loadings include low downwash velocities which allow efficient ground operations below a hovering tilt rotor aircraft with improved personnel safety, and autorotation capability to achieve a safe descent/flare in the event of a total power loss.

The tilt rotor concept is also unique in that the conversion corridor, (i.e., the band between the minimum and maximum flight speeds throughout the rotor-mast tilting process) is broad (typically greater than 60 knots) and non-critical. Furthermore, the conversion may be stopped and reversed, or the aircraft may be flown in steady-state at any point in the conversion corridor. This feature is expected to provide great flexibility in field operations, enhance survivability because of low-speed agility, and permit the performance of STOL operations at greater than VTOL gross weights.

The two tiltable low-disc-loading rotors, located at the wing tips, are driven by two or more gas turbine engines. The engines may be located in the tilting nacelles mounted at the wing tips, or may be fixed with respect to the wing. A cross shaft system mechanically links the rotors so that power sharing for maneuvers or control is possible and asymmetric thrust in the event of single engine malfunction is avoided. Independent control of each engine/rotor can be maintained should simple cross-shaft failure occur (due to combat damage, for example). The rotor/nacelle tilt mechanism is provided with redundant fail-safe design features, thus preventing asymmetric tilt conditions and binding of the mechanism in any fixed position.

The stiffness and mass distributions of the rotor/nacelle/wing/dynamic drive system are tuned to remain above resonances in the range of operating rotor rotational speeds. Special emphasis is placed on meeting both the structural and dynamic stability requirements. Therefore, the aircraft was designed to be free of rotor stall flutter and wing/pylon/rotor dynamic coupling problems throughout the entire tilt rotor operational flight envelope.

The control system in hover is similar to that of a "side-by-side" twin rotor helicopter. Fore and aft cyclic pitch provides longitudinal control and (differentially applied) yaw control, eliminating the need for a tail rotor. Differential collective pitch provides roll control. In the cruise flight mode, control is achieved with conventional airplane control surfaces, although the presence of the rotor cyclic and collective controls would permit, with further development, the use of the rotor in cruise for control augmentation, aircraft stabilization, and gust alleviation. A program for phasing of control functions from helicopter to aircraft type controls as a function of mast angle is applied during conversion.

OBJECTIVES

The following proof-of-concept objectives, directed toward basic tilt rotor air vehicle technology verification, have been established for the current XV-15 Tilt Rotor Research Aircraft Project.

- Experimentally explore, through flight research, current tilt rotor technology that is of interest for the development of useful, quiet, and easily maintainable Army tilt rotor aircraft. Verification of the rotor/pylon/wing dynamic stability and aircraft performance over the entire operation envelope are key elements of this objective.
- Experimentally establish a safe operating envelope and initially assess the handling qualities of the Tilt Rotor Research Aircraft as a basis for the follow-on advanced flight research.
- Investigate tilt rotor gust sensitivity.
- Investigate the effects of tilt rotor disc loading and tip speed on downwash and noise and the impact on hover mode operations.

An advanced flight research program has been formulated to expand the state-of-the-art of tilt rotor handling qualities, operations, and configuration design. These flight investigations will be performed to achieve the following objectives:

- Perform thorough evaluations of the handling qualities of the Tilt Rotor Research Aircraft

and assess areas where additional tilt rotor handling qualities research is required including incorporation and evaluation of gust load alleviation systems and fly-by-wire control systems.

- Determine V/STOL navigation/guidance requirements and evaluate automatic landing systems.
- Develop and evaluate potential methods and procedures for efficient near-terminal operations to reduce congestion and noise and to increase safety.
- Provide data for consideration of design and operational criteria for potential military and civil tilt rotor aircraft relative to certification requirements and Aeronautical Design Standards (ADS).
- Investigate alternate or advanced rotor concepts or configuration modifications.

Further flight research will be performed with the Tilt Rotor Research Aircraft to explore the various aspects of use of this concept for typical Army missions – the ultimate objective of this program. As part of investigating mission suitability, all related technological characteristics (such as maintenance, human factors, and safety) will be explored.

IMPLEMENTATION PLAN

The tilt rotor concept appears especially well suited for military applications for reconnaissance and surveillance, search and rescue, utility, and medium-lift missions. IOC dates established for vehicles to satisfy these missions will set the pace for the further development of all pertinent technologies.

The plan to accomplish the necessary technical goals is composed of the following eight elements, which are required prior to entering a production prototype program:

- Methodology development
- Model tests
- Full-scale component and subsystem tests
- Air vehicle design studies (for incorporation on XV-15 or new aircraft as appropriate)
- Flight simulation investigations
- Systems integration and proof-of-concept flight tests
- Advanced technology investigations flight tests
- Mission suitability flight tests.

Tilt rotor technology was initiated with the XV-3 flight program in the 1950s. This program was based on the direct application of existing helicopter analyses. Although the XV-3 program demonstrated the feasibility of the tilt rotor concept at low speeds, several problems requiring further research were identified in the areas of rotor/pylon/wing stability, flight stability, and performance. The recognition of these problems led to the derivation of sophisticated tilt rotor analytical models during the late 1960s, particularly in the structural dynamics, rotor performance, and stability and control disciplines. These mathematical models were developed by the integration of several basic sciences to account for the interdependence of the aerodynamics, dynamics, structures, propulsion, and control factors affecting the tilt rotor aircraft. Continued refinement of this tilt rotor methodology is required within each technology in support of the overall progam. Plans call for improving the quality of analytical techniques used for determining the various structural dynamic and aerodynamic interactions, as well as improving the capability of utilizing complex computer programs as design tools. The availability of new experimental data will enable continual upgrading of the analytical methods.

The application of model test techniques toward verifying the performance, structural stability, and flight stability of the tilt rotor aircraft will continue as an essential part of the program. Improved modeling techniques, comprehension of scale effects, the development of effective methods of isolating the model from wind tunnel wall effects during low speed or transition flight, and techniques for properly simulating ground effects and atmospheric turbulence are required. Specific areas of research related to the tilt rotor aircraft include the continuing development of the rotor system (hingeless, gimballed, etc.), determination of rotor/pylon/wing dynamic stability characteristics of new configurations, investigations of rotor wake/wing interaction and tail interaction effects, and the development of stability augmentation and gust alleviation systems. State-of-the-art aeroelastic modeling techniques are used to provide the dynamic scaling necessary for some of these tests.

Investigations of the performance, dynamic stability, and functional characteristics of full-scale tilt rotor aircraft components will continue as part of the

XV-15 program to minimize the technical and cost risks. Among the components and subsystems to be examined are the transmission and drive system, the rotor control system including the applicability of a fly-by-wire control system, and the rotor/pylon/wing assembly. Correlation with model test data and analytical data will continually be examined to assess the quality of the technology base and to evaluate the requirement for additional fundamental research.

In addition to the design of the research aircraft, continuing air vehicle design studies are required to determine the adequacy of tilt rotor technology to optimize configuration design for an Army airmobility mission. Tradeoffs in performance, weight, cost, noise, and other factors (such as maintainability or transportability) must continue to be weighed. Achieving unique design requirements imposed by the particular mission will rely on the application of the advances to the state-of-the-art made in each of the technologies derived from the foregoing methodology and test programs.

XV-15 RESEARCH AIRCRAFT

A complete integration of all technologies is being conducted in the design of the XV-15 Tilt Rotor Research Aircraft. This aircraft (shown in figure AT–6) will be the minimum size vehicle capable of demonstrating the generic flight characteristics of the concept. Design and configuration data for the XV-15 are shown in table AT–A. A stability and control augmentation system (SCAS), a high-sink-rate landing gear, a ground adjustable variable incidence horizontal tail, an emergency egress system, a force feel system, and fail-safe or fail-operational components and subsystems are included in this design. Provisions for advanced avionics for automatic VTOL terminal area operations (V/STOLAND) and a gust load alleviation system are also incorporated. Research capability will be assured by providing high control power, adequate installed power, capability of over 2000 lb of payload in the VTOL mode, adequate cabin volume for instrumentation or other mission payload, and more than 1 hr of fuel for research missions (up to 1.1 hr of hover flight).

The rotors, transmissions, and drive systems have been designed to enable variations of tip speed to study its effects on hover performance, noise, stability and downwash and on cruise performance, gust sensitivity and noise.

Flight simulation investigations have been conducted and additional tests are planned throughout the tilt rotor program. The simulations provide a means of assessing handling characteristics, configuration variations, flight operation procedures, emergency procedures and SCAS and GLAS characteristics. The simulators will also be used for pilot familiarization.

The fabrication and proof-of-concept flight tests of the research aircraft are important milestones in the Army tilt rotor technology program. Basic flight safety and flight envelope boundary exploration will be conducted by the contractor. Additional flight research to examine structural stability, assess handling qualities and study generic tilt rotor aircraft flight characteristics and the effects of gusts, tip speed, and disc loading will be performed jointly with NASA. These flight investigations form the foundation for the advanced flight research program.

The Army and NASA will continue with the joint flight test program beyond the basic proof-of-concept flights. Research into gust and load alleviation systems, handling qualities, alternate or advanced rotor concepts, and flight control systems are planned. The data resulting from this investigation may be instrumental in formulating design and operational criteria and specifications for advanced Army air mobility tilt rotor applications. Certain flight phenomena may warrant additional analytical investigations, model tests, flight simulations, and further flight tests.

The Tilt Rotor Research Aircraft will be used as a tool to assess Army air mobility mission suitability. Factors such as hover out-of-ground-effect, climb capability, loiter and cruise performance, maximum speed capability, handling qualities, maneuverability, pilot work load, autorotation capability, maintenance requirements, and noise, radar, IR, and visual detection signatures will be examined. The XV-15 Tilt Rotor Research Aircraft was designed and built under a low cost shop approach using a maximum of existing hardware and therefore is not optimally sized or configured for the particular requirements for any specific Army air mobility mission, the vehicle is sufficiently versatile to demonstrate and explore many of the various mission performance and operational factors. The Tilt Rotor Research Aircraft is also a suitable test bed for advanced VTOL avionics for all-weather operation and area navigation investigations. The application of the STOL mode and the use of intermediate rotor mast positions will be

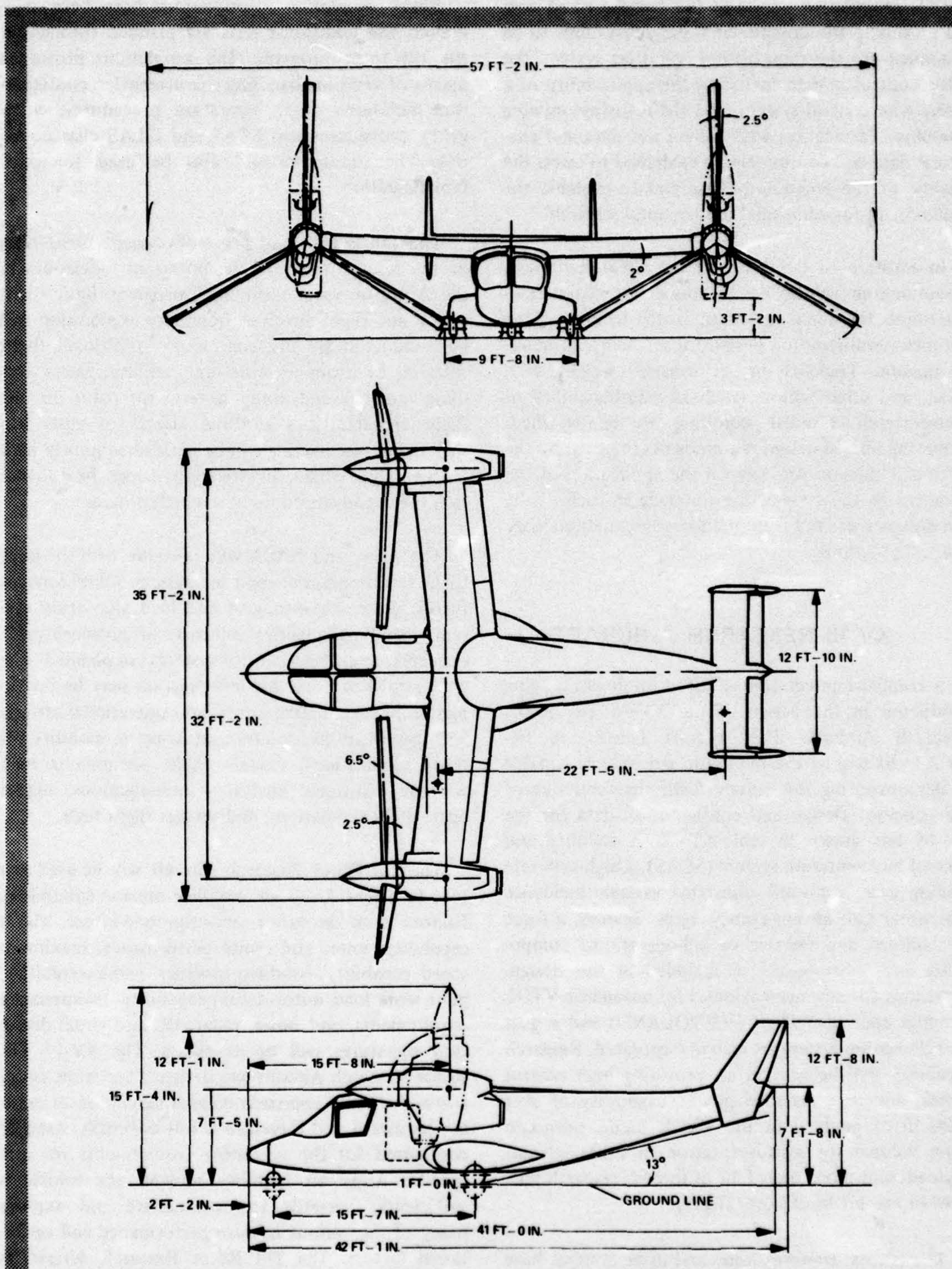


Figure AT–6. XV-15 Tilt Rotor Research Aircraft.

TABLE AT–A
DESIGN AND CONFIGURATION DATA OF XV-15 RESEARCH AIRCRAFT

CHARACTERISTICS	DESIGN	REMARKS
Design/Max VTOL GW	13,000/15,000 lb	10 fps Rate of Sink
Useful Load at Design VTOL GW	3,345 lb	Incl. 1007 lb of Research Equip., Crew-400 lb, 1 hr Mission Fuel
One Hour Rsch. Mission Operating Wt	12,057 lb	Crew-400 lb, Fuel 1150 lb + 10 min Res.
Wing Loading	77 psf	@ 13,000 lb DGW
Rotor Disc Loading	13.2 psf	@ 13,000 lb DGW
Rotor Design Tip Speeds		
Hover/Cruise	740 fps/600 fps	@ 565 rpm/458 rpm
Limit Speeds		
Cruise (level flight)	332 knots (TAS)	@ 16,400 ft DGW, Max Torque Limit, Contingency Power
Dive	364 knots (TAS)	@ 12,800 ft DGW, M = .575
Helicopter Mode	140 knots (TAS)(Max)	@ Mast Angle = 75 degrees, S.L., Cruise Torque Limit
Airplane Mode	120 knots (TAS)(Min)	@ 1.2 V_{stall}
Maximum Conversion Rate	90 degrees/11 sec	
Limit Load Factors		
Symmetrical Flight	+3.0g–1.0g	Design GW
Asymmetrical Flight	+24g–0.8g	Design GW
Symmetrical Flight	+2.3g–0.75g	Maximum GW
Noise @ 500 ft Sideline	90 PNdb	Most Noise-Critical Condition
Endurance (Min)	1.1/2.2 hr	Hover @ S.L. Std/Cruise @ 10,000 ft
Design Life		
Airframe	5,000 hrs	
Rotor	1,500 hrs	
XMSN & Dynamic Components	3,000 hrs	
Dimensions		
Overall Height	15.3 ft	Hover Mode
Overall Width	57.2 ft	Rotors Turning
Overall Length	42.1 ft	Without Instrument Boom
Wing		
Area	169 sq ft	
Span	32.17 ft	Between Rotor Axes
Dihedral	2 degrees	
Aspect Ratio	6.12	
Chord	5.25 ft	
Thickness Ratio	.23	
Sweep	–65 degrees	Forward from Root
Flap/Flaperon Area	5.5/10.1 sq ft	
Horizontal Tail		
Total Area	50.25 sq ft	
Span	12.83 ft	
Aspect Ratio	3.27	
Elevator Area	13 sq ft	
Vertical Tail		"H" Tail, Two Vertical Panels
Total Area	50.5 sq ft	
Span	7.18 sq ft	Per Panel
Sweep of 1/4 Chord	31.6 degrees	Upper Section
Effective Aspect Ratio	2.33	
Rudder Area	7.5 sq ft	Both Panels
Rotor (Type)	Gimballed	Hub Spring Flapping Restraint
Number of Blades	3	
Diameter	25 ft	
Blade Chord	14 in	Constant
Total Solidity	.089	
Engines (2)(Type)	LTCIK-4K	Lycoming T53, Mod.
Takeoff SHP/SFC	1,550/.57	SHP per Engine
NRP SHP/SFC	1,250/.600	

studied during this flight test period. It is expected that the proof-of-concept, and some of the advanced flight investigations, of the XV-15 aircraft will provide sufficient verification of tilt rotor analytical methodology and small scale emperical data to allow initiation of an Army System Development Program based upon the tilt rotor concept. As in the application of the helicopter and fixed wing aircraft, a continuing supporting research and technology program will be conducted to maintain world leadership in this field.

ROTOR SYSTEM RESEARCH AIRCRAFT

GENERAL

Since the mid-1960s, the Army and NASA have conducted several independent studies to determine methods of improving the capabilities of rotor flight research on an economical and timely basis. Results of these studies prompted the establishment of an Army/NASA working group in January 1971 to determine if a commonality existed in both agencies for rotor flight research, and if so, what system would best provide a capability to achieve common research objectives. It was concluded that an instrumented flying test bed, capable of accepting and testing new rotor concepts as they became available for "proof of concept" flight research, offered the best solution.

The Rotor Systems Research Aircraft (RSRA) will fly as a pure helicopter, a compound helicopter, and as a helicopter simulator, where the aircraft wings, drag brakes, auxiliary propulsion engines, and elevator will be used to react the main rotor being tested. This last mode provides a quick, thorough, and cost-effective method of mapping the performance characteristics of test rotors.

CONCEPT CHARACTERISTICS

GENERAL

To be the versatile research tool desired, the RSRA will require unique capabilities. The various subsystems that will provide these capabilities are described below.

CONTROL SYSTEM

The versatility of the research aircraft is dependent on the type of control system incorporated into the vehicle. The RSRA has fixed-wing-type aerodynamic control surfaces, in addition to the conventional rotor controls. A computer-controlled fly-by-wire system, operating through a mechanical system, is used since it provides the ability to readily adapt the control system, through the computer logic, to the control requirements of a wide variety of rotor systems. This system will permit rapid modification in the control authority of both the rotor controls and the aerodynamic surface controls in order to provide the proper integration and control harmony necessary for flight tests of rotor wing compound helicopter concepts. The control system will incorporate provisions for performing preprogrammed evaluation maneuvers such as, for example, repeatable step or ramp inputs in order to rapidly and accurately acquire flight test data. The computer-controlled fly-by-wire system will be used by the research evaluation pilot and the mechanical system by the safety pilot.

DATA SYSTEM

An essential feature of the Rotor System Research Aircraft will be its ability to obtain in-flight measurements of the vehicle state (speed, load factor, etc.) and the forces and moments of the rotor, wing, auxiliary propulsive system, and tail rotor system. Sensors installed in the vehicle will be compatible with the Langley Research Center developed Piloted Aircraft Data Systems (PADS). These and other data recording or transmitting devices will be compatible with the Langley Research Aircraft Ground Station in order to provide on-line monitoring of tests as well as rapid and detailed assessment of rotor and vehicle characteristics.

VIBRATION ATTENUATION SYSTEM

Since the research aircraft will be flown with numerous rotor systems covering a wide range of dynamic characteristics, the vehicle will have a mounting system that is adaptive to the different rotor systems, along with a system to attenuate significant rotor system vibratory loads. Two different vibration attenuation systems are being developed. This system is an active rotor balance isolation system that will provide a system capable of attenuating vibrations from almost all rotor systems.

EMERGENCY CREW ESCAPE SYSTEM

Although not directly related to rotor systems research, an emergency escape system for the three crew members will be provided. The technique being

used will provide pyrotechnic blade severance and sequential upward extraction of the crew. A second emergency mode will allow blade severance followed by automatic flight control adjustment to allow the aircraft to return to base as a fixed wing.

OBJECTIVES

The objective of the Rotor Systems Research Aircraft Project is to develop two versatile flight vehicles to provide economical rotorcraft research in the real and dynamic environment of flight. These research aircraft will provide the research capabilities that cannot be duplicated in ground-based facilities and that previously have been prohibitively costly because of the need for specialized vehicles for each new rotor system.

The versatility of the Rotor Systems Research Aircraft will permit:

- Economical flight research of a wide variety of promising new rotor concepts.
- Verification of new rotorcraft technology offering potential solutions of existing or future problem areas.

IMPLEMENTATION PLAN

GENERAL

The implementation plan is defined in terms of vehicle development, other development activities, and vehicle operations. These elements are directed toward refining and successfully integrating desired characteristics of demonstrated technology into a flight research aircraft.

VEHICLE DEVELOPMENT.

Vehicle Definition. A technical team of AMRDL and NASA-Langley personnel reviewed the research requirements of each agency and to define the vehicle characteristics necessary to meet the requirements. The team defined the performance capabilities, systems requirements, and special features for an aircraft capable of performing the desired research mission.

Predesign Studies. A request for proposals was issued to the helicopter industry to obtain predesign studies to:

- Define vehicle configurations that would accomplish the Government's objectives and goals.
- Assess tradeoffs between technical requirements and costs.
- Identify and assess potential technical risk areas and indicate technology development required.

Two respondents, the Bell Helicopter Textron and the Sikorsky Aircraft Division, United Aircraft Corporation, were awarded contracts for these studies in December 1971. The study results identified two possible vehicle configurations to accomplish the objectives of the Government.

Vehicle Design, Fabrication, and Test. The vehicle specifications developed from the contracted studies and in-house efforts were used to establish the final vehicle specifications and requirements for issuance of an RFP in March 1973, for the vehicle design and fabrication. Bell Helicopter and Sikorsky Aircraft responded to the RFP. In September 1973, the Sikorsky Division was selected for negotiations and was awarded a contract effective November 5, 1973. Sikorsky finalized its design for the Critical Design Review held in June 1975. Fabrication of Aircraft No. 1 is complete and Aircraft No. 2 is nearing completion. Flight testing will begin in September 1976. Aircraft delivery is scheduled for October 1977. A picture of the helicopter configuration is shown in figure AT–7; design and configuration data are listed in table AT–B.

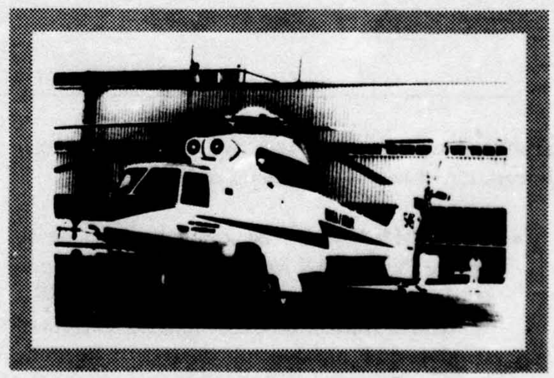


Figure AT–7. RSRA-Helicopter configuration.

Developmental Activities for Future Rotor Systems. To date, several developments have been completed and several others are underway to insure incorporation capability of future rotor systems on the RSRA. Development of these capabilities is necessary to assure that the personnel conducting research after delivery of the aircraft will have the necessary

TABLE AT–B
RSRA DESIGN AND CONFIGURATION DATA

Stress Gross Weight	26000 lb	Lower Horizontal Stabilizer (Except Helo)	
Design Gross Weight, Compound		Area	88.3 sq ft
Mission	26200 lb	Span	22.5 ft
Gross Weight, Hover Mission	18400 lb	Chord (mean)	3.93 ft
Weight Empty, Compound		Elevator Area	12.5 sq ft
Configuration	20968 lb	Incidence	±8° geared to stabilizer
Weight Empty, Helicopter			
Configuration	14633 lb	Upper Horizontal Stabilizer (Except Helo)	
Main Rotor System (Sikorsky H-3)		Area	17.2 sq ft
Diameter	62 ft	Span	8.58 ft
Number of Blades	5	Chord	2.04 ft
Chord	1.52 ft	(Helo)	
Normal Tip Speed	685 ft/sec	Area	35.4 sq ft
Blade Twist	-8	Span	13.25 ft
Tail Rotor System (Sikorsky H-3)		Chord	2.78 ft
Diameter	10.6 ft	Vertical Stabilizer	
Number of Blades	5	Area (Upper and Lower)	101.1 sq ft
Chord	0.612 ft	Span	15.9 ft
Normal Tip Speed	685 ft/sec	Chord (mean)	6.83 ft
Blade Twist	0	Rudder Area	24.8 sq ft
Wing		Turboshaft Engines	
Area	369.9 sq ft	Type	T58-GE
Span	45.1 ft	Military Rating, SLS	1400 HP
Airfoil Section	NACA 63_2415	Main Gearbox (Sikorsky H-3)	
Aspect Ratio	5.52	Power Rating, 30 Minutes	2500 HP
Variable Incidence Range	-9° to +15°	Turbofan Engines	
Taper	0.66	Type	TF34-GE-400A (2)
		Military Rating, SLS, Static	8159 lb
		Military Rating, SLS, 300 knots	5340 lb

analytical tools and test techniques to assure proper integration of new rotor systems of the RSRA.

- *NASTRAN Model.* The contractor has developed a NASTRAN finite-element model representing major structural elements of the RSRA air vehicle system. It has 9,000 static degrees of freedom and 300 dynamic degrees of freedom. This model was used for structural sizing of members, calculations of internal loads, and for calculating natural vibration modes of the vehicle in the frequency range necessary for tuning the airframe for the installation of new rotor systems.

- *Active Rotor/Balance Isolation System Model.* An intensive analysis was conducted during the first 9 months of the contract to establish detailed specifications for the active isolation system. Analytical models were established to represent the impedance of the isolation system and impedances of several representative research rotors. These impedance models were incorporated into systems dynamics models, which were used for system design purposes, taking into account the influence of active isolation parameters on the following areas: airframe, vibration, control, mechanical stability, aeroelastic stability, and stability augmentation. These models provide the personnel conducting research operations with the capability to determine the isolator system adjustments required when unusual rotor systems are installed.

- *Control System Capability.* As a part of the development of the control system, additional flight control capability is being incorporated. The RSRA will be capable of operating in a

high-resolution model following control mode. This capability offers to the rotor systems researcher the flexibility of prescribing aircraft control motions that are tailored to the specific rotor system being investigated. In addition, the RSRA control system will be capable of providing automatic stabilization of the rotor condition (forces and moments) and/or the vehicle flight path. This capability allows the precise setting of test conditions during research measurement flights.

- *Simulation.* Basic equations of motion and supplementary data have been developed and programmed into a flight dynamics analytical model, fixed base pilot-in-the-loop simulation at Langley Research Center, and moving base pilot-in-the-loop simulation on the Flight Simulator for Advanced Aircraft at the Ames Research Center. The data include results of model wind-tunnel test. Analysis and simulation capabilities include flight as a helicopter, as a compound helicopter, and as an airplane. These simulations have been used for evaluating rotor blade severance and will be used for evaluating effects of new rotors.

OTHER DEVELOPMENT ACTIVITIES

General. Technology for the Rotor Systems Research Aircraft has been demonstrated. However, effective utilization of the vehicle will require development of supporting technology in order to conduct a wide range of flight research programs with confidence both as to technological contribution and safety. Prior to flight tests, rotor concepts will undergo logical steps of preparation including detailed analysis and appropriate wind tunnel tests. Several programs underway in support of current rotor developments will yield methods and equipment very generally applicable in this preparation stage.

Helicopter Model System for the Langley V/STOL Wind Tunnel. The Langley V/STOL tunnel has proven especially suitable for investigation of helicopter system characteristics. A generalized helicopter rotor model has been developed under contract and will obviate significant delays in performing rotor test programs, utilizing much more fully the potential of this tunnel. The model accommodates rotor diameters up to 12 ft and is designed for both performance, stability and control testing. Some features that indicate its generality are:

- Range of fuselage contours and representations of gunship, transport, and commercial helicopter configurations.
- Articulated, rigid, or teetering rotors.
- Provisions for wing installation with high, mid, and low positions.
- Provisions for tail rotor and tail surfaces.

The model was delivered with the RSRA fuselage and a four-bladed articulated rotor. Testing at the Langley Research Center was successfully completed confirming the RSRA design.

Rotor Dynamics Wind Tunnel Model. An existing wind tunnel model for study of rotor aeroelasticitiy was improved to provide a general hub fixture. These improvements allow accommodation of 10-ft-diameter elastic rotors, either articulated or hingeless soft inplane. The fuselage is rigid with variable inertias and the model mount incorporates a variable stiffness feature. This model was modified for use in the Langley Transonic Dynamics Tunnel (but not at transonic speeds). However, it may be used in any tunnel of comparable size and with sufficient power for the model rotor drive system.

Flight Simulation Math Model. A flight simulation math model has been developed at the Langley Research Center. It includes an aeroelastic blade representation, body degrees of freedom, and wake representation. Output includes loads, stability and control data, and identification of potential aeroelastic instabilities. This simulation is being used to help define the test program.

Rotor Feedback Study. In December 1974, Sikorsky Aircraft completed a contracted study consisting of analytical and simulation studies followed by in-flight demonstrations of techniques for employing blade motion electronic feedback signals as primary control input shaping functions. This investigation provided engineering data concerning signal conditioning techniques, allowable gains, and stability characteristics of various feedback signals in the control network. In addition, the results have general application in the areas of rotor gust response suppression, high-speed helicopter control sensitivity, and compound helicopter rotor-wing lift control.

VEHICLE OPERATION

Ground Tests. The contractor will conduct shake tests on the RSRA airframe and perform appropriate proof, functional, operational, and calibration tests on the air vehicle and its subsystems. These tests include full system tests of the crew escape system at the Air Force's sled track facility at Holloman Air Force Base, New Mexico. Upon completion of these ground tests, 10 hr of operational tiedown tests shall be conducted. An additional 10 hr of tiedown tests will be conducted after the installation of the Active Rotor Balance Isolation System.

Calibration and Acceptance Flights. Prior to Government acceptance of the two Rotor Systems Research Aircraft in the fourth quarter FY77, the contractor will conduct 92 hr of flight tests at the contractor's facility and at NASA-Wallops Flight Center. These tests will demonstrate the structural integrity and safety of flight, develop the recommended procedures for flight in both normal operation and emergency situations, and establish the basic stability and control characteristics of the aircraft. Government pilots will participate in the contractor's flight test program.

Research Flights. Scheduling of specific research flights is not presented herein; however, such plans will be developed by personnel responsible for research programs during the aircraft development phases.

Operations Support. Ground support services for supporting R&D flight operations will be provided by contract under subsequent R&D programs.

ADVANCING BLADE CONCEPT

GENERAL

The operational flight envelope of conventional helicopters is typically limited by vibratory loads in the rotor system as retreating blade stall and compressibility problems are encountered. The flight envelope may be expanded somewhat by increasing rotor sizes and/or adding wings to generate the required lift. Auxiliary propulsion to provide horizontal thrust in combination with wings and "rotor slowing" permits additional expansion of the flight envelope. The major disadvantage of these concepts is that the wings add weight, drag, and complexity.

A theoretical study of a coaxial rigid rotor system, undertaken by Sikorsky Aircraft in 1965, indicated that such a system has potential to overcome or reduce the limitations of conventional and "winged" helicopters. This approach called for lateral displacement of each rotor's resultant lift onto the advancing side of its respective disc, by an amount required to maintain optimum airload distribution. This concept, designated the Advancing Blade Concept (ABC), together with the means of selectively positioning the lift vectors, was awarded US patent No. 3,409,249 in 1968.

From 1967 to 1969, Sikorsky Aircraft and United Aircraft Research Laboratories conducted a series of experimental programs to develop and test dynamically scaled ABC hardware. It was indicated from these and other investigations that the ABC system was practical and that full-scale hardware could be developed.

A 40-ft-diameter rotor system, designed for 14,500 lb lift and 230 knots maximum speed, was built, whirl-tested, and observed to be aeromechanically stable and structurally sound. To evaluate the system in forward flight, the instrumented ABC rotor was installed in the NSA/Ames Research Center 40 ft by 80 ft wind tunnel and tested at 25 combinations of flight conditions up to a maximum advance ratio of 0.91 and up to an advancing blade tip Mach number of 0.83. Results verified the aerodynamic and structural potential of this concept.

The Army awarded a contract to Sikorsky Aircraft in December 1971 to design, fabricate, and test a helicopter that incorporates the ABC rotor system. The program, currently in progress, is directed toward demonstrating the feasibility and evaluating the performance of the ABC rotor system through flight test.

CONCEPT CHARACTERISTICS

The Advancing Blade Concept is a co-axial, counterrotating, "rigid" rotor with several potential advantages over "standard" rotor systems. With this concept, the aerodynamic lift in forward flight is carried primarily on the advancing blades and is not limited to that which can be developed on the retreating side of the rotor disc. This largely eliminates the problems of retreating blade stall and enhances maneuver capability. As with other coaxial helicopters, a tail rotor is not required for antitorque purposes; yaw control at lower speeds is produced by differential main rotor

torque. The "rigid" rotor without flapping hinges, lead-lag hinges, and associated hardware eliminates the maintenance normally required for these components. Super-stiff rotor blades preclude excessive deflections under high loads and permit rotor slowing for high-speed applications where the advancing blade tip Mach number must be kept below approximately 0.85. Potential advantages may be summarized as follows:

- Ability to overcome some of the aerodynamic limitations of conventional rotors
- Superior maneuverability
- Reduced complexity
- Deletion of tail rotor and associated hardware
- Compact configuration
- High-speed capability with horizontal thrust augmentation

The ABC rotor demonstrator aircraft was designed to demonstrate the entire range of rotor capabilities using only the basic rotor system for low-speed operation as a pure helicopter, but employing turbojets to explore high-speed capability of the same rotor design.

The 6-bladed, coaxial rigid rotor system is essentially the same as that used in full-scale tests conducted in the NASA–Ames 40 ft X 80 ft wind tunnel. Figure AT–8 is a general arrangement drawing of the XH–59A ABC demonstrator aircraft. Specific charzcteristics of the demonstrator aircraft are also shown.

Power to the rotor system is supplied by a UACL/ Pratt & Whitney PT6T-3/T-400/Twin Pac rated at 1800 shaft horsepower and driving through a transmission system derated to 1500 horsepower. This system provides dual engine safety and sufficient power to hover out of ground effect at maximum gross weight at sea level with an ambient temperature of 90° F. Auxiliary thrust for maximum performance is provided by two Pratt & Whitney J60 turbojets. These units are not installed during the pure helicopter portion of the evaluation.

The flight control system combines control of the coaxial rotor system with elevator and rudder control. The cockpit controls consist of a cyclic stick for pitch and roll control, a collective stick for vertical control, and pedals for directional control. The collective stick changes the blade pitch angle equally on each rotor for rotor thrust control. The cyclic stick

	PURE HELICOPTER CONFIGURATION	AUXILIARY PROPULSION (TURBOJETS) CONFIGURATION
FLIGHT GROSS WEIGHT – lbs.	9710	11714
ROTOR DIAMETER – ft.	36	36
DISK LOADING – lbs./ft.^{2}	9.5	11.5
TOTAL ROTOR SOLIDITY RATIO	.127	.127
DRIVE SYSTEM DESIGN HORSEPOWER	1500	1500
MAX. STRUCTURAL DESIGN SPEED – kts.	196	345
DESIGN LIMIT LOAD FACTOR – G's	2.5	2

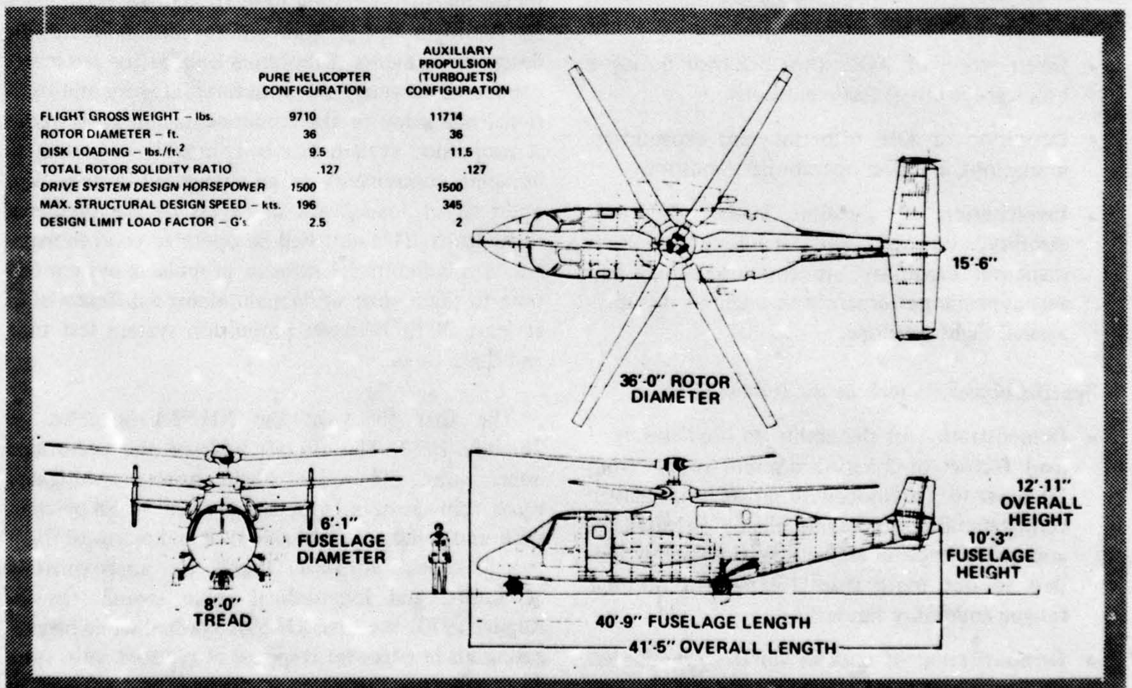


Figure AT–8. XH-59A ABC demonstrator aircraft general arrangement.

changes the blade angle cyclically and equally on each rotor for rotor pitch and roll moment control. The pedals change the blade angles collectively, but equal and opposite, on each rotor (differential collective pitch) for directional control. Unique to the ABC rotor system is the ability to change the cyclic pitch blade angles of each rotor differentially to load or unload the advancing, high dynamic pressure side of each rotor to optimize rotor efficiency and minimize blade stresses. Full rotor lift capability can be maintained in high-speed flight; high-lift capability is available for load factor development at all speeds. In addition to rotor controls, the longitudinal cyclic stick can be connected directly to the elevators and the pedals are connected directly to rudders. Geared tabs are installed on the rudders and elevators to reduce the stick and pedal forces. The tabs have an electrically actuated link, controlled from the cockpit, to permit trimming the stick and pedal forces. A rotor differential collective pitch trim control is also installed in the cockpit to trim differences in rotor torque in level flight.

OBJECTIVES

The following general objectives have been established for the XH-59A Advancing Blade Concept Flight Research Program:

- Investigation of ABC rotor behavior during a broad spectrum of test conditions.
- Definition of ABC rotor inherent capabilities, limitations, and best operational conditions.
- Investigation of dynamic loads, vibrations, stability, control, and handling qualities, maneuver capability, autorotational entry and aerodynamic performance throughout the operational flight envelope.

Specific objectives include the following:

- Demonstration of the ability to hold sustained load factors of 2.5 *g* at discrete speeds from 70 knots to 170 knots with satisfactory maneuvering stability, acceptable blade tip clearances, and stress levels in all critical components limited to not more than 150 percent of their fatigue endurance limits.
- Demonstration of cockpit vibratory levels that do not exceed MIL-Spec requirements. This demonstration is to be accomplished without an active vibration isolation system installed.
- Demonstration of flying qualities that are compatible with MIL-Spec requirements. This demonstration is to be accomplished without the need for unduly complex types of stability augmentation or control systems.

IMPLEMENTATION PLAN

In December 1971, the Eustis Directorate of AMRDL awarded a contract to Sikorsky Aircraft Division of United Aircraft to design, fabricate, and flight test an ABC-configured research aircraft. Specific design requirements were kept to a minimum to provide the necessary tradeoff flexibility in arriving at a balanced, but, of necessity, highly compromised design. Aircraft target design speed was 140 to 170 knots in the helicopter mode and up to 300 knots in the compound helicopter mode with two J-60 turbojets providing horizontal thrust. Target hover design point was hover out of ground effect at sea level 95° F at design gross weight in the compound helicopter configuration.

Model testing in conjunction with moving base simulator studies and engineering analyses were used in the design phase. These tools will be used intermittently on an as-required basis to increase confidence for the flight test program and to assist in identifying design refinements. Laboratory and fatigue tests were conducted to verify the structural integrity and functional adequacy of the components and subsystems. A propulsion system test bed, capable of testing all dynamic components as an integrated system, was operated at load levels in excess of the predicted flight loads. This unit will be operated so as to maintain a mimimum 2:1 ratio of propulsion system test time to flight time while maintaining a differential of at least 30 hr between propulsion system test time and flight time.

The first flight of the XH-59A occurred on 26 July 1973. The aircraft hovered and performed hover turns. Subsequent flight testing investigated rotor rpm changes from 103 percent to 88 percent, stick and pedal reversals, sideward and rearward flight to 10 knots, forward flight to approximately 30 knots, and longitudinal spike inputs. On 24 August 1973, the first XH-59A crashed while investigating blade edgewise response at reduced rotor rpm. The pilot was attempting to trim the aircraft at 30 knots when the aircraft experienced a pitch-up divergence at approximately 28 knots. The aircraft

settled to the ground tail first and was extensively damaged but the pilots received only minor injuries. Following a detailed accident investigation, design changes were made to the flight control system. The ABC program was restructured and a new contract awarded in November 1974. The new contract calls for resumption of flight testing as a basic helicopter, with the modified flight control system installed and flight testing with jet engines installed for auxiliary propulsion. Ground tests, wind tunnel tests, and analytical studies will also be made to further investigate and substantiate the flight worthiness of the test aircraft. A unique feature of the new contract requires that pre-flight predictions of key aircraft parameters agree with actual flight data within specified tolerances. Where significant differences occur, flight testing will stop until the reasons for the difference is understood and the mathematical model revised to produce results in consonance with flight data.

On 21 July 1975, flight testing of the basic helicopter with the modified control system installed was begun. Low speed (up to 80 knots) tests were conducted to verify the adequacy of the modified control system. Test results showed that the modified control system resolves the problem that caused the crash of the first ABC aircraft. Test results also showed good correlation with pre-flight analytical predictions for most parameters of interest. As of this writing, the ABC aircraft has been flown to speeds of 140 knots and trends of measured technical parameters are favorable. The aircraft has demonstrated rapid control response, significantly low noise signature and positive rotor blade edgewise damping in the most adverse conditions tested.

As additional flight test data becomes available, a major effort will be made to properly assess the merits of this rotor concept and to identify its inherent strengths and weaknesses. One of the most important questions to answer is the following: What is truly germane to the ABC and what is incidental to only the test program? In trying to answer this question, several others must be answered first.

- What was the magnitude of the design compromise in building the research aircraft to provide both conventional and high-speed flight?
- What performance gains might have been realized by pre-tilting the rotor/transmission forward to reduce drag for conventional speeds, or by tilting the rotor/transmission backward for optimizing high-speed flight?
- What would be the overall advantage of using high-modulus material in the blade spars to reduce weight, drag, and vehicle height?
- What is the feasibility of reducing the size of the transmission/rotor shaft through redesign or new materials?
- What penalty is associated with using two J-60 turbojet engines for horizontal thrust and two PT-6 engines for lift rather than two convertible shaft engines as combined lift/thrust engines?
- How much rotor maneuver "muscle" is actually usable, i.e., what maximum angular acceleration is the rotor capable of producing within the constraints of blade tip clearances and stresses and as limited by opposing moments generated by a horizontal stabilizer sized to meet static stability criteria?

To answer some of these questions, flight test data will be analyzed in depth. Load predictions and design criteria will be compared against actual measurements. Estimates will be made as to the amount of "over" or "under" design of components and translated into weight savings or weight penalties. Vibration characteristics will be examined to determine the vibratory *g* levels at the pilot station and at a transmission mount. Dynamic interaction distorting the loads picture, i.e., phenomenon not believed germane to ABC will, hopefully, be sorted out. Aerodynamic performance will be reviewed critically in an attempt to calculate rotor L/D ratios, figure of merit, propulsive force limitations, specific range, etc. Control power, damping and response, will be compared with MIL-Spec requirements and other helicopters. In addition, many qualitative assessments will be made as to the maintainability and reliability implications, the compact configuration, lower noise signature, etc.

Based upon successful flight test results, several development programs to better exploit ABC rotor technology have been planned. Goals of these programs include high-speed maneuverability investigations and development of handling qualities suitable for the Advanced Scout Helicopter, and the Advanced Aerial Weapons System. Analytical and design efforts are being considered in the following areas:

- Development of ABC rotor blades made from high-modulus material
- Concurrent development of a lightweight rotor hub

- Rotor hub fairings for reducing hub drag
- Development of rotor/flight control systems
- Development of vibration reduction systems
- Rotor slowing and stopping

Rotor blades made of high-modulus material would be fabricated and subjected to a battery of structural tests. A lightweight rotor hub employing tension/torsion straps would be fabricated and tested in conjunction with the high-modulus rotor blades. Wind tunnel tests of full-scale rotating rotor hub fairings would be conducted. Rotor control and flight control systems tailored to specific Army missions would be designed, verified on a moving base simulator, and fabricated. Breadboard hardware would be flight tested. Vibration reduction systems would be designed and the leading concept fabricated and flight tested. A slowed/stopped rotor model would be designed, fabricated, and wind tunnel tested. Fabrication and full-scale tests of a slowed/stopped ABC rotor system would be conducted after efforts identified above have been completed. A convertible engine propulsion system capable of supplying power to provide both lift and thrust has been considered. An ABC aircraft equipped with a convertible engine propulsion system, is illustrated in figure AT–9. Open props would be replaced with fans, depending upon the mission application.

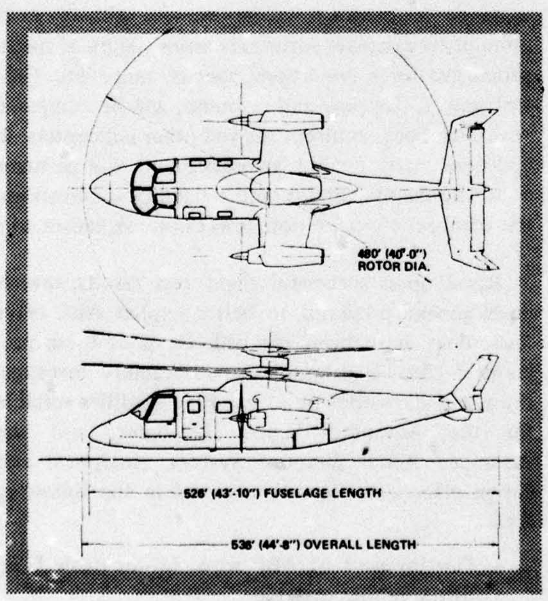


Figure AT–9. ABC aircraft equipped with a convertible engine propulsion system.

ADVANCED STRUCTURES TECHNOLOGY DEMONSTRATOR

GENERAL

Through research and development programs conducted over the past ten years, the potential for improvements in aircraft structural performance and capability through the use of composite structures and advanced design concepts has been demonstrated conclusively. The improvements, which include reduced component weight and cost and increased system reliability, maintainability, safety, survivability, and productivity, have been evidenced both in fixed-wing and rotorary wing aircraft components. In most of these components, however, the method has been to directly substitute the advanced structure for an existing structure in the aircraft. Thus, a "substituted design approach" has been employed for these advanced structures. Although this approach has been instrumental in demonstrating these structures, with some performance improvements being achieved, it has not been possible to optimally design the structure to its maximum efficiency and potential nor to accurately ascertain realistic component costs due to interface limitations with the existing aircraft and the necessity to duplicate the replaced component's performance and characteristics (contour, weight distribution, stiffness, hard points, etc.). In order to minimize cost and to maximize the weight and performance advantages of composites, the composite structures must be applied to the major assembly such as a fuselage. Thus the manufacturing break and component interface joints are selected for ease of manufacturing and joining to suit composite materials rather than the former metallic structure. Thus a synergistic weight savings can occur through use of an original design with composites. Although an additional weight savings could occur if one resized the entire aircraft for decreased structural weight, the ASTD will utilize an existing rotor, drive train and engine (dynamic-propulsion system – DPS). The weight improvement due to the use of composites will permit improved hover performance due to a lower mission weight or increased payload. An additional significant weight saving for the vehicle is obtained when the weight saving of a particular component enables resizing of other components on the vehicle. This "synergistic effect" yields an overall smaller helicopter to accomplish the same mission. Unless the entire aircraft is examined when considering the use of advanced composite materials and design concepts, much of their advantage will be lost.

The ASTD aircraft is intended to demonstrate the true synergistic effect of advanced composite materials and concepts in aircraft structures through an "integrated design approach." The ASTD program will enable the use of the latest structural design requirements and the latest analysis methodology, and will permit integration of the various advanced structural components and concepts developed individually under separate R&D programs into one aircraft system. The program will also broaden the data base for composite material applications and manufacturing technology and will stimulate Government and industry to timely use of these materials and manufacturing processes.

CONCEPT CHARACTERISTICS

The ASTD, although a demonstrator aircraft, shall be designed to the latest military specification requirements for a utility helicopter. The vehicle shall be designed for a structural load factor equivalent to the most stringent maneuver and flight load conditions. Reliability, maintainability, safety, survivability, and crashworthiness are major characteristics in which improvements are sought. The structural concept is shown in figure AT–10.

Innovate design characteristics and manufacturing techniques will be a key to the maximum effective use of advanced composite materials.

OBJECTIVES

The ASTD Program is intended to demonstrate the technology improvements achievable in rotary wing aircraft through the applications of advanced composite materials and structural design concepts to both primary and secondary structures. Specific technical objectives for the ASTD include the following:

- *Reduced Structural Weights.* An 18 percent total structural weight savings for the selected advanced technology components developed in the ASTD Program over conventional structures technology components meeting identical design requirements is sought.
- *Reduced Life Cycle Cost.* A 10 percent total production cost reduction, based on a 1000 aircraft buy in the 1980 timeframe, for the advanced technology components is desired. A reduction in operational costs for these components of 15 percent will be sought.

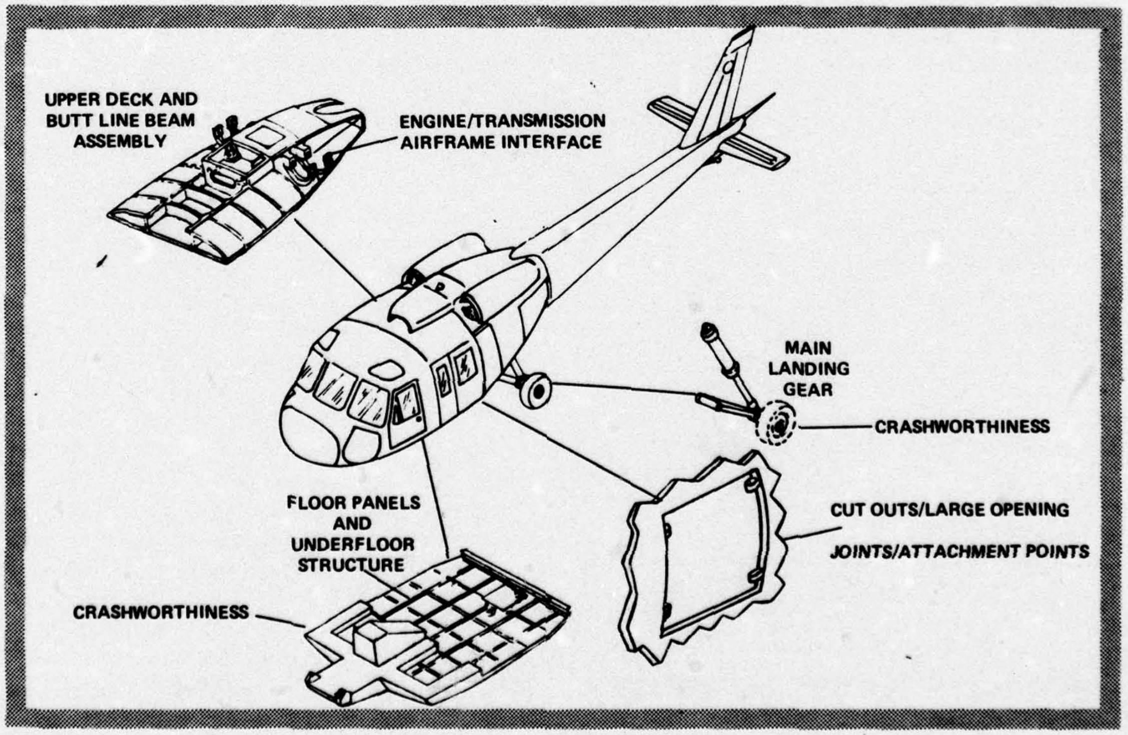


Figure AT–10. Advanced composite structural concepts.

- *Improved Ballistic Damage Tolerance.* 14.5 mm damage tolerance for all flight critical components and 23 mm HEI damage tolerance for the main rotor blades and fuselage is desired.
- *Fail-Safe Structure.* All flight critical components shall meet fail-safe structural design criteria.
- *Reduced Radar Reflectivity.* Design condition for all composite components.

IMPLEMENTATION PLAN

The ASTD program shall be a three-phased program to be accomplished through the design, fabrication, structural tests, and flight demonstration of a utility helicopter extensively incorporating advanced composite materials and design.

INTRODUCTION

TECHNOLOGICAL DISCUSSION

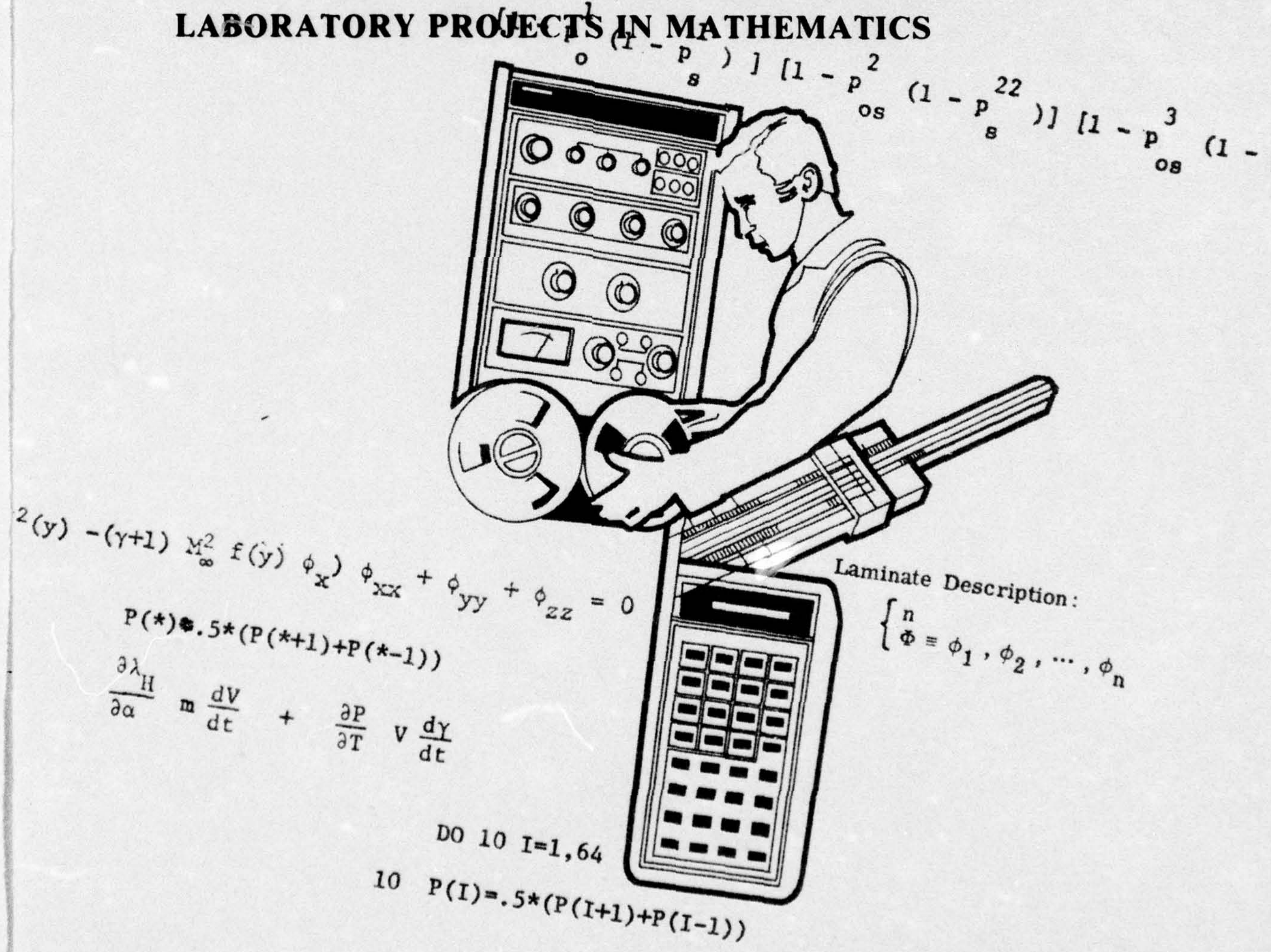
AREAS OF APPLICATION

SUBDISCIPLINES

TECHNOLOGICAL PROGRAM DIRECTION

LABORATORY PROJECT SELECTION PROCESS

LABORATORY PROJECTS IN MATHEMATICS



INTRODUCTION

Mathematics has long played a central role in the intellectual and technological history of mankind. This statement hardly begins to convey the impact of mathematics on modern civilization, nor account for the dynamic application of mathematical sciences to other disciplines such as engineering, physical sciences, medicine, economics, and management.

The development of physical sciences and the advancement of modern technology continue to use sophisticated mathematical techniques and concepts. The research efforts in this Plan indicate the needs of mathematics so as to enhance, facilitate, and strengthen theoretical, experimental, and numerical investigations. In particular, appropriate mathematical knowledge and computer science are indispensable to airmobile research, as well as to risk assessment. Mathematical concepts that are of particular importance include partial and ordinary differential equations (including deterministic and stochastic cases), optimization theory, finite difference methods, finite element method (including Rayliegh-Ritz-Galerkin techniques), boundary value problems, relaxation methods, Bayes decision theory, and parameter identification. Also, in solving problems numerically, parallel processing has a profound influence on the computational capability. For instance, the computer ILLIAC IV is faster than the IBM 360/67 by a factor of around 200. Consequently, solutions to problems that are technically as well as economically infeasible via conventional computers can now be obtained. However, this unique capability cannot be realized by the sequential logic. In order to utilize such a computing structure efficiently, a prospective problem must be amenable to parallel, rather than sequential, processing. Consequently, basic and expository research in these areas, as well as parallel algorithmic efforts, constitutes a relevant component of the fundamental sciences in airmobile investigation.

TECHNOLOGICAL DISCUSSION

AREAS OF APPLICATION

Aerodynamics, structures, propulsion, and decision analysis constitute the basic domain to which much of the Laboratory research efforts are devoted. The end results of these efforts contribute to fill the technological needs and requirements of advanced airmobile systems. From a mathematical point of view, these results provide technology for the following major areas of application:

- Design of systems, such as high-speed rotor design
- Resource allocation, such as RPV program source selection analysis
- Performance effectiveness, such as optimal diagnostic procedure for malfunctioning system
- Risk analysis for systems, such as tilt rotor research aircraft application

One of the missions of this Laboratory is to establish the requirements and to fill the voids of advanced airmobile systems. The unique behavior of the rotor draws much of the Laboratory's design efforts such as to design an improved transonic tip configuration. Due to limitation on available resources, a significant problem to which the Laboratory directs its attention is resource allocation, for if the distribution of resources is "proper," then it maximizes the chances of meeting the performance/mission requirements. Also, another problem that the Laboratory management has to contend with is the uncertainty of program success associated with each management decision. Therefore, resource allocation and risk analysis are important due to their overall impact on the Laboratory. Performance analysis enables engineers and scientists to determine the criteria under which a given system can be performed more efficiently.

SUBDISCIPLINES

Although the Laboratory research is quite diversified, in abstract mathematical settings the basic essential mathematical tools for airmobile research can be classified within four mathematical subdisciplines:

- Numerical analysis associated with differential equations and/or algebraic systems
- Mathematical programming
- Theory of linear and nonlinear operations
- Probability theory

On the basis of the above statement, it appears that these are the only relevant mathematical concepts for airmobile research. In essence, they encompass almost every field of mathematics. For instance, the ingredients for differential equations and numerical analysis are the classical real analysis and theory

of complex variables. These in turn, have the theory of set, theory of real and complex numbers, algebra, and Euclidean geometry as their building blocks in a finite dimensional setting.

In view of the Laboratory's applications, numerical analysis plays the central role in the Laboratory airmobile research, as is substantiated by the following:

- Newtonian mechanics dictates that every dynamical system that obeys the classical law of physics can be written in an equivalent mathematical equation.
- The end result of most numerical schemes applied to differential or integral equations gives rise to an algebraic system.
- Numerical approach provides an immediate means to obtain an approximate solution to physical problems within a reasonable time frame.

It is well known that the computational aspects of practical mathematical programming present some problems for a present-generation computer. In particular, in dynamic programming if the amount of resources is large and the increment is small, a tremendous amount of memory (including temporary), as well as the number of arithmetic operations, is required.

Although the numerical approach in obtaining an approximate solution to a given problem has its own advantages, there are some difficulties associated with computational physics. An obvious disadvantage of numerical solution is its discrete form, to which only a limited amount of analytical studies can be made. On the other hand, the analytical approach toward the solution would eliminate computational problems and preserve the intrinsic analytical properties of the solution. Therefore, an analytical result is desirable for further studies, such as the sensitivity of the parameters involved and their ranges of validity.

[illegible]

LABORATORY PROJECT SELECTION PROCESS

GENERAL

The Project Selection Process philosophy and elements are presented in Section TI. This section applies that process to the mathematical science discipline. The OPR is not an objective of the Plan, but is provided to show the AMRDL procedure used in the selection of projects within a discipline as constrained by the Army's R&D budget.

OBJECTIVES

The near-term program objectives of the various subdisciplines within the mathematical science discipline can be established as follows:

- To overcome computational barriers of CPU time, cost, and storage limitations imposed by conventional computers through research on parallel processing with applications to airmobile research efforts, such as high speed rotor design, and structural analysis of materials containing cracks.
- To enhance computational capability on resource allocation by investigating the suitability of dynamic programming via parallel processing.
- To exploit the generic properties of a mathematical structure associated with logic modeling concepts for maintenance analysis.
- To research analytical methods preserving the intrinsic analytical properties possessed by closed form solutions in solving airmobile problems such as structural dynamics of a rotor.
- To perform mathematical analysis on performance effectiveness such as direct operation cost modeling of air vehicles.
- To strengthen the Laboratory capability in risk analysis and maintenance analysis through exploitation on probability theory and establishment of mathematical foundation.

PROGRAM PRIORITIES

General. Table MA–A presents, in a prioritized listing, the mathematical science technology subdisciplines, technical developments, and system effectiveness criteria. This triple structure is developed to facilitate the identification of major R&D program thrusts which support the near-term technical objectives.

Technology Subdisciplines. The mathematical science technology subdisciplines are represented by the following major topical areas:

- *Numerical analysis* – a branch of mathematics whose theory underlies the development of numerical computation process for obtaining, in general, an approximate solution to a mathematical expression.

- *Mathematical programming* – a branch of applied mathematics that can be further partitioned into sub-branches, based on the given cost function and its associated constraints, such as integer programming, linear programming, nonlinear programming, and dynamic programming. The latter deals with a multistage decision process. Solution of a mathematical programming problem is that solution or those solutions which maximize (or minimize) the cost function.

- *Theory of linear and nonlinear operators* – addresses the intrinsic properties, deduced by deductive reasoning, which pertain to a function or transformation. The operator notion implies that the domain as well as the range of a transformation need not be the real numbers and is generally a vector space. An operator for which the distributive law holds is called a linear operator. For example, an m by n matrix is a linear operator whose domain is an n-th dimensional vector space and whose range is a vector space of dimension, m. Similarly, a differential equation governing the behavior of a rotating helicopter blade defines an operator having the set of all possible responses (solutions) as its domain and the loading (forcing functions) belonging to the range.

- *Probability theory* – a theoretic treatment of observable events occurring in connection with non-deterministic phenomena.

Technical Developments. The technical developments identified in table MA–A are the relevant mathematical procedures developed for the implementation of the mathematical science objectives and goals.

System Effectiveness. In the area of system effectiveness, the primary influence of mathematical science is the optimal realization attained via the technical developments and the objective determination of life cycle cost and improved airmobile system design, in support of the Laboratory's research efforts.

Priorities. With reference to table MA–A, the mathematical science subdisciplines, technical developments, and system effectiveness criteria are presented and ordered by priority-Roman Numeral I, representing the highest priority.

MAJOR THRUSTS/RATIONALE

Assessment of the priority listing in table MA–A in conjunction with the mathematical objectives stated above, reveals that the first priority major

TABLE MA–A
PRIORITIZED MATHEMATICAL SCIENCE OPR ELEMENTS

TECHNOLOGY SUBDISCIPLINE	PRIORITY	TECHNICAL DEVELOPMENTS	PRIORITY	SYSTEM EFFECTIVENESS	PRIORITY
• Numerical analysis associated with differential equations and/or algebraic systems	I	• Parallel algorithms for both direct and iterative methods	I	• Optimality	I
• Mathematical programming	II	• Resource allocation algorithms	II	• Life cycle cost	II
• Theory of linear and nonlinear operators	III	• Optimal fault-isolation technique	III	• Airmobile system design	III
• Probability theory	IV	• Serial Algorithms	IV		
		• Analytical approach	V		
		• Risk analysis schemes	VI		

thrust is to develop mathematically valid and practically useful mathematical techniques for the attainment of optimality, life cycle cost, and improved airmobile system design through exploitation of and research on the above listed subdisciplines. Laboratory research effort strongly supports this thrust. For example, in aerodynamics research, the end result of most numerical schemes applied to differential or integral equations gives rise to a large algebraic system. Closed form solution to this type of problem is usually impractical if not impossible. So one seeks an approximate solution to the problem utilizing the capability of present-generation high-speed computer. Then the problem is to develop and exploit an efficient iterative method that is compatible with the given computing structure.

The second priority major thrust is to establish mathematical structure, for existing as well as conceptual airmobile systems, and to deduce from the model those generic properties contained within the system. For example, a task under the Laboratory's reliability and maintainability investigatory efforts was to establish the feasibility of logic modeling concepts for maintenance analysis. This modeling concept is an engineering innovation. A mathematical structure of a logic model for a physical system was established and from which some useful generic properties were obtained, leading to optimal diagnostic strategy.

LABORATORY PROJECTS IN MATHEMATICS

INTRODUCTION

The research program in mathematical science is at the (6.1) research level to increase mathematical knowledge and to strengthen R&D capability. This in-house effort is conducted primarily by AMRDL Directorates and the Advanced Systems Research Office.

DESCRIPTION OF PROJECTS

Project 1F161101AH45-TA IV is a research effort conducted to exploit and apply state-of-the-art mathematics in support of Laboratory research efforts, to develop a technology base in numerical analysis and computation techniques associated with parallel computation capabilities (e.g., ILLIAC IV computer at Ames), and to advance mathematics in areas applicable to airmobile R&D. The efforts under this project are directed toward the development and exploitation of numerical schemes for solving numerically transonic flow problems, as well as to investigate differential equations exhibiting decreased damping with increased amplitude of oscillation and to establish mathematical structure on functional systems for maintenance analysis.

FY77 FUNDS DISTRIBUTION

The resources that would be required to pursue the objective of the mathematical science R&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.1 mathematical science FY77 R&D effort is $65,000 and represents 2% of AMRDL R&D 6.1 funds.

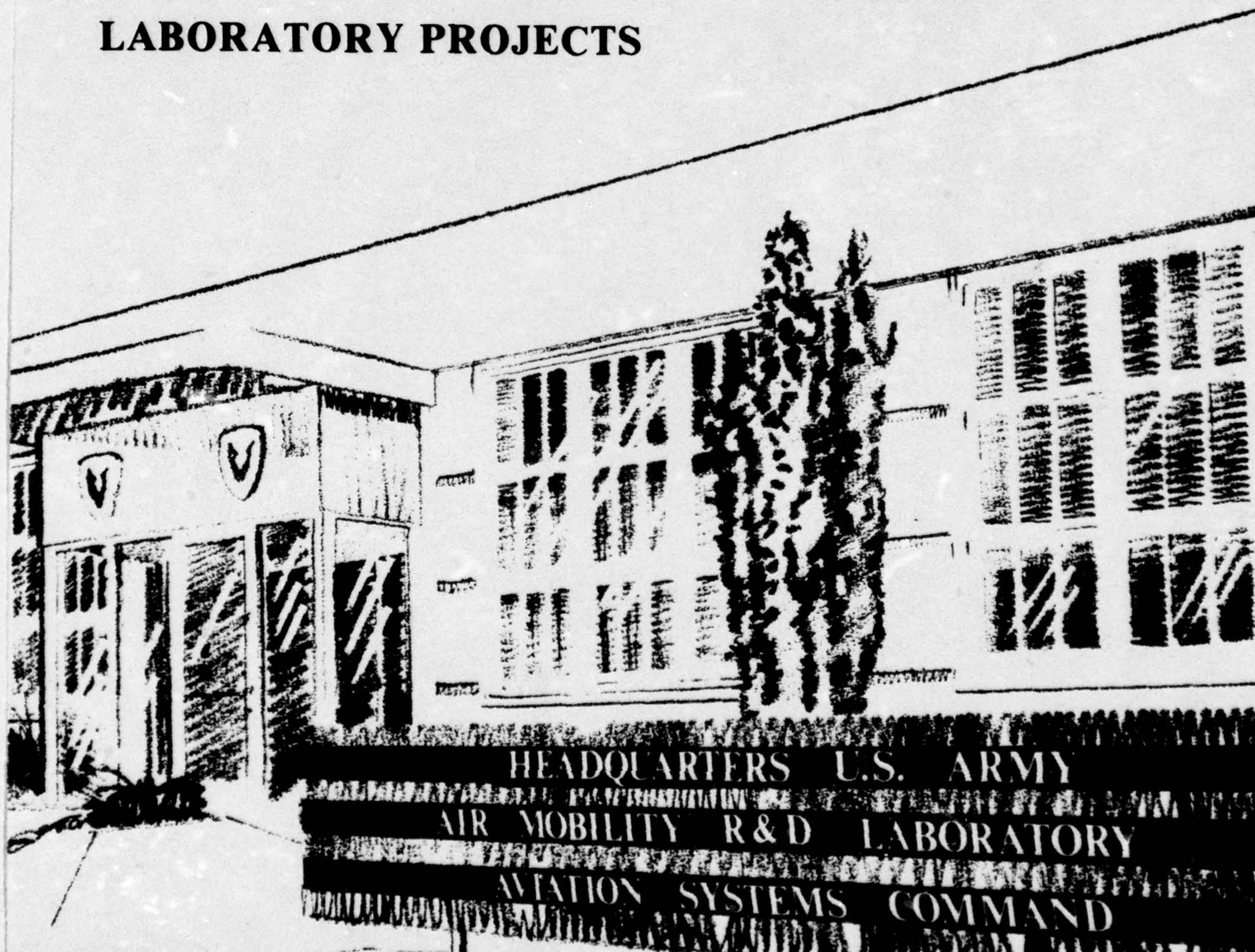
INTRODUCTION

MANAGEMENT

PRIMARY PROJECT MISSION

COLLATERAL MISSION RESPONSIBILITIES

LABORATORY PROJECTS



INTRODUCTION

The superiority of future Army airmobile systems depends on the availability and exploitation of new scientific knowledge. The development of an appropriate technology base to meet projected requirements can be assured by formulating a time-phased prediction of technical potential, set forth in an orderly sequence of coordinated R&D activities in the many disciplines and technologies required to develop airmobile systems. All the previous sections deal with airmobile systems and technologies. This section addresses the process that interrelates all the previous sections and results in an R&D program that provides the technology for current and future systems.

MANAGEMENT

The U.S. Army Air Mobility Research and Development Laboratory is the R&D Laboratory of the U.S. Army Aviation Systems Command. This Laboratory is primarily involved in research, exploratory development, and portions of advanced development through demonstration of technology. AMRDL is the means by which AVSCOM maintains a strong, relevant technology base for new development and improvement of airmobile systems.

Program management of the Aircraft Systems Synthesis Project is the responsibility of the Advanced Systems Research Office (ASRO) of AMRDL Headquarters, located at Moffett Field, California. The Advanced Systems Research Office includes 18 professional staff positions, each responsible for one or more of the respective technologies or disciplines addressed in the technology section of the Plan. Also participating in the Aircraft Systems Synthesis Project are the Systems Research Integration Office (SRIO), located in St. Louis, Missouri, and the Preliminary Design Group of the Eustis Directorate, located at Fort Eustis, Virginia.

[illegible]

As indicated in the introduction of this section, the primary mission of the Aircraft System Synthesis Project is the development of an appropriate Army aviation R&D program. The process whereby this mission is accomplished is presented in figure SY–1. Each of the dark bordered "steps" represents major task assignments to either ASRO and/or SRIO.

The process begins with the analysis of Army aviation systems requirements. This is accomplished by individual members of the ASRO and SRIO staffs who have been assigned the responsibility to interface with a particular TRADOC proponent school (e.g., ARMOR/AAH and ASH) or project manager. This activity can result from an official Required Operational Capability; from pre-ROC dialogue with TRADOC schools; from LOAs; from the emergence of a new technical capability; or from the requirement for product improvement. In any case, this analysis activity is coordinated with TRADOC and other appropriate DARCOM commands.

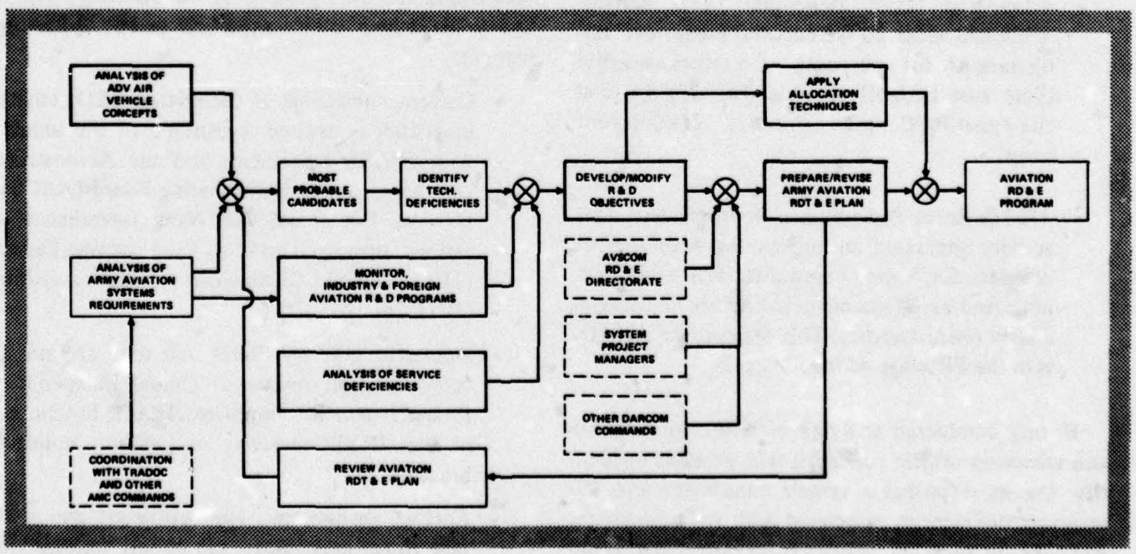


Figure SY–1. Aircraft systems synthesis process.

Having addressed the subject of requirements, the next task in the process involves an analysis of advanced air vehicle concepts to develop viable candidates that satisfy the requirements. This activity requires the conduct of preliminary systems design engineering (PSDE), in which vehicle and subsystem performance are "traded off" against life cycle costs. Credible PSDE output requires validated methodology; thus, an important ingredient in this activity is the development and maintenance of vehicle weight, performance, and life cycle cost models. As indicated in previous sections, PSDE activities may range in scope over all of the system life cycle and may be initiated for various purposes during any phase of the life cycle. To illustrate this point, examples of recent analyses employing PSDE include the following systems:

- Helicopter Commonality Feasibility Study: This effort provided technical support and guidance to an evaluation of the feasibility of interservice helicopter commonality. Five basic helicopter types and numerous design missions within each type were studied. These systems represent future equipment at a stage earlier than any phase of the life cycle management model.
- Mini-Manned Aircraft System: This activity developed configuration and life cycle costs for six (6) concepts, including rotary wing, ducted fan, and fan-in-wing.
- Advanced Scout Helicopter: This activity developed some 20 systems and subsystem configurations for purposes of performance/life cycle cost tradeoff analysis. This system is in the post-ROC, pre-engineering development stage.
- AH-1Q Rotor Performance Improvement: This activity generated an engineering development program for a new composite fiber rotor with improved aerodynamic performance and survivability characteristics. This system, the AH-1Q, is in the PIP stage of the life cycle.

Having conducted analyses of both requirements and advanced vehicle concepts, it is possible to identify the most probable vehicle candidates and the technical deficiencies associated with each candidate. Examples of such deficiencies from early PSDE activities are:

- Lack of advanced engine technology to provide a small, low-cost engine in the 5–50 horsepower range.
- Undefined handling qualities requirements for low level night operations and nap of the earth flying as applied to the AAH and ASH.
- Undefined maneuverability requirements for UTTAS.

Such technical deficiencies, when identified, are reviewed for possible inclusion in the aviation R&D program planning.

Another source of technical deficiencies which may impact the aviation R&D program planning is the operating fleet. Service deficiencies are monitored by various elements of AMRDL and reflected in the R&D activity where appropriate. Examples of this type of service-generated input are:

- Tail boom structural/dynamics problems
- Engine compressor, turbine disk, and turbine blade problems
- Main rotor adhesive bond difficulties
- Excessive IR signature
- Bearing and seal problems

A primary element in the development of an appropriate R&D plan and program is current intelligence regarding similar activities in other U.S. Government agencies, domestic industry, and foreign establishments. This portion of the Aircraft System Synthesis Project is accomplished in the following manner:

- Current knowledge of the related R&D activity in NASA is assured by means of the unique Army/NASA agreement, and the Aeronautics and Astronautics Coordinating Board (AACB). U.S. Air Force and U.S. Navy interchange is assured through Technical Coordinating Papers (TCP) and Joint Commander's Technical Group (JCTG) activities.
- Domestic industry R&D activities are monitored through review of annual Independent Research and Development (IR&D) brochures, on-site IR&D reviews, and *ad hoc* industry briefings.
- Foreign technology, state-of-the-art and military threat capabilities, are closely followed by the Foreign Intelligence Office. This permanent

position, located in the Advanced Systems Research Office at Headquarters, AMRDL, takes cognizance of foreign efforts in areas and disciplines affecting Army air mobile capability and integrates the information obtained into the Army's aviation R&D program. This office utilizes Army, Department of Defense, and national intelligence sources to accomplish its mission.

At this point in the process, the Army aviation RDT&E Plan preparation is initiated. Inputs are selected from AVSCOM RD&E Directorate, system project managers, and other DARCOM major subordinate commands. These inputs are reviewed and combined with the deficiencies identified above, and the R&D near- and long-term objectives are developed or modified (these objectives are presented for each of the respective disciplines in the technology section of this Plan). The Plan is then completed and distributed internally, and to industry on request. Since the technology requirements and the threat are dynamic, the Plan is updated annually and thus, the process is continuous in nature.

The RDT&E Plan is a comprehensive guide to all viable alternatives for generating required air mobile system capabilities. It is not a specific R&D program. Development of the aviation R&D program evolves from the near-term objectives of the Plan after the constraints imposed by the budget, available personnel, and facilities have been considered. This process is referred to as resource allocation and requires some type of rational project selection process, whether it is quantitative or qualitative. Several attempts to develop a quantitative technique have been made, with limited success. The current procedure is qualitative in nature and involves participation of each ASRO technical specialist, and the senior management team of AMRDL. The current resource allocation technique requires a clear definition of near-term Laboratory objectives, priority of objectives and a rationale supporting the priority (OPR). These OPRs are prepared by the appropriate ASRO member for each technical discipline and are utilized by AMRDL senior management to allocate resources and thus, structure the R&D program. (See OPR procedure in the Technology Introduction section.)

In the technology section of the Plan, each technical discipline is subdivided into a set of subdisciplines, and the near-term technical objectives are presented. It is clear that there is an interdependency between objectives, technical subdisciplines, vehicle subsystems, and eventual system cost effectiveness. Ideally, resource allocation could be quantitatively related to incurred cost (through subsystems) and to effectiveness (through subsystems) and the respective quotient minimized. In lieu of the quantitative ideal, priorities of technology major thrusts to be represented in the R&D program are developed.

COLLATERAL MISSION RESPONSIBILITIES

In addition to the primary mission described in the previous section, the Aircraft Systems Synthesis Project has additional collateral responsibilities, some continuous in nature, others of an *ad hoc* nature. These additional responsibilities complement the primary mission in all cases, and are discussed in the following paragraphs.

Unsolicited proposals, from industry and academic institutions regarding airmobile technology, are submitted directly to Headquarters, AMRDL for consideration in the overall R&D program planning. Furthermore, unsolicited proposals are also submitted from the Army Research Office (ARO), for evaluation and possible funding by that organization. The Advanced Systems Research Office is responsible for processing all such proposals, either reviewing or selecting other AMRDL elements to review them. This activity involves approximately 175 proposals a year, with 40 percent of these being submitted by ARO.

Project manager support is both a continuing and *ad hoc* activity in the Aircraft Synthesis Project. The SRIO organization provides a continuous PM support function, having assigned specific personnel to each project (e.g., UTTAS, AAH, etc.). PM support from ASRO and the Eustis Directorate Preliminary Design Group is provided as required, with frequent contributions to such projects as the T-700, AH-1Q, ASH, and UH-1/AH-1 Projects.

AMRDL is chartered by Commander, DARCOM and AVSCOM, to perform technical risk assessments of major programs, on their request or that of the Director, AMRDL. The Aircraft System Synthesis Project provides for such analyses. Recent technical risk assessments have been conducted on the following programs:

- HELLFIRE
- UH-1/AH-1 Rotor System

- Tilt Rotor Aircraft/Tilt Rotor Flight Safety
- Aquila RPV
- Rotor System Research Aircraft
- OH-58 Rotor Mast Failure

In addition to the above collateral responsibilities, ASRO and SRIO initiate special technical projects that are directed at R&D program or methodology improvements. The near-term goals of these projects are as follows:

- Research high-output light-weight low cost engine for aircraft and RPVs.
- Develop technical requirements for accomplishing low level night operations.
- Develop analytical treatment of direct operating cost (DOC) model.
- Investigate composite structure failure mechanisms in fatigue environment.
- Initiate laboratory program applying engineering psychology technologies to air mobility.
- Prepare technical development plan for research usage of simulators supporting aircraft development through 1990.

LABORATORY PROJECTS

INTRODUCTION

Aircraft Systems Synthesis project has as its objective, the generation of a unified, coordinated research and development program responsive to Army aviation system requirements and major science and technology objectives.

This work is primarily accomplished at the Headquarters, AMRDL by the Advanced Systems Research Office and the Systems Research Integration Office with some preliminary design support from the Eustice Directorate.

DESCRIPTION OF PROJECT

Project IF262209AH76–TA VIII is an exploratory development effort with four major areas of effort as described below:

- Evaluate advanced air vehicle and subsystem concepts for official Army requirements; in-house computerized aircraft design capability will be expanded to improve accuracy, increase applicability to additional aircraft concepts, cover additional mission and performance requirements, and permit determination of additional off-design capabilities.
- Analyze Army aviation R&D programs. Continue the development of risk analysis methodologies and the conduct of technical risk assessments. Participate in program risk assessments, design reviews, and evaluation of technical plans and problems. Conduct analyses of proposed aircraft and weapons applications.
- Orderly planning and programming of Army aviation R&D.
- Provide a focal point for airmobile expertise and represent U.S. Army to industry for R&D activities (e.g., industry proposals, IR&D direction, etc.) with particular emphasis on technology transfusion.

FY77 FUNDS DISTRIBUTION

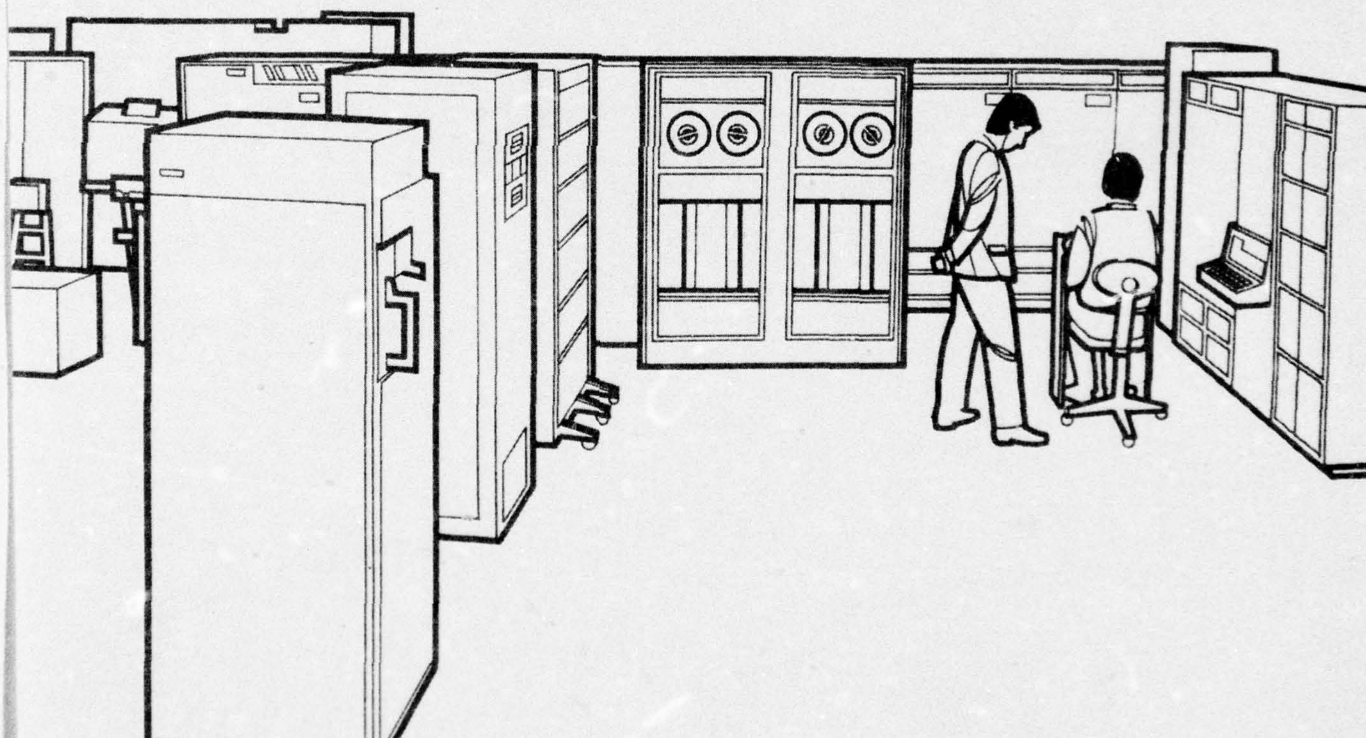
The resources that would be required to pursue the objective of the aircraft systems synthesis P.&D efforts as presented in the technical discussion are shown and discussed in Section RR. Those funds do not represent the current R&D program. The Command Schedule Guidance budget for the 6.2 aircraft systems synthesis FY77 R&D effort is 1.07 million dollars and represents 7% of AMRDL R&D 6.2 funds (excluding Project IF262201DH 96 Aircraft Weapons Technology funds).

INTRODUCTION

SCIENTIFIC RESEARCH

FUNDAMENTAL SCIENTIFIC RESEARCH

BASIC SCIENCES



INTRODUCTION

The activities in the area of research (6.1) addressed, thus far, in this Plan have been directed toward specific technological objectives even though they are not necessarily associated with the development of one particular aircraft system. However, fundamental relevant research in physical, mathematical, environmental, and life sciences is also needed to add to the total knowledge from which new military air mobility capabilities are derived. Research activities in those scientific areas that are basic to air vehicle technology generally originate with the worker at the "bench level." Research and management need the resources, responsibility, authority, and flexibility to permit the researchers to explore at least the more promising of these technological opportunities in limited scope, even though there might be no obvious application or established potential payoff.

SCIENTIFIC RESEARCH

FUNDAMENTAL SCIENTIFIC RESEARCH

Fundamental scientific research constitutes a prerequisite to the development and improvement of Army aircraft systems. It is necessary for the formulation of new and improved concepts and provides direct and indirect fallout into all of the technology areas identified in this Plan. It must be performed concurrently with technology investigations to establish, refine, and advance the state-of-the-art of air vehicles technologies. The establishment of fundamental principles and data in all physical sciences provides the basis for advances in all air mobile system efforts.

The fundamental research programs at the AVSCOM are pursued only within those scientific areas that relate to present and planned programs and needs.

Basic research in aerodynamics, structures, propulsion, and human factors has essential application to air mobility and aeronautical technology elements. Without this effort toward development of the technology base, only marginal increases in Army aircraft performance, stability, and control can be achieved. Research in these fundamental sciences must be continued to maintain Army competence and contact with emerging significant ideas and potential advances of science; to enable recognition of scientific and technological opportunities; and to provide an essential feeder line to exploratory development.

BASIC SCIENCES

The range of basic sciences that is applicable to and that supports Army Aviation technology is very broad, encompassing the entire scope of physical and life sciences. Most of the areas of the applicable physical sciences are outlined in the Military Themes documents of the Army Research Office. The primary AMRDL effort in fundamental science is discussed below.

LASER VELOCIMETER TECHNOLOGY

Rotary wing fluid mechanics technology is severely limited by current techniques for theoretical prediction, or experimental measurement, of the fluid state in the vicinity of the rotor. The object of this project is to provide army scientists and engineers an additional opportunity to maintain and increase their competence by doing original work in areas suiting their talents, thereby promoting a vigorous internal research program of the highest caliber. The unsteady turbulent boundary layer on two-dimensional oscillating airfoils has been shown to contain the essential features of the rotor dynamic stall process which is the primary source of helicopter torsional rotor vibratory loads and a major source of the vertical and horizontal components of rotor hub forces and blade stresses. The laser velocimeter technology provides a unique opportunity to determine the sequence of events in the unsteady dynamic stall process, and then the opportunity to evaluate modifications designed to delay or soften the stall process. This capability can then be used to verify theoretical studies which define methods for reducing acoustic detectability, provide improved performance and improve the technological base for rotary-wing aerodynamics.

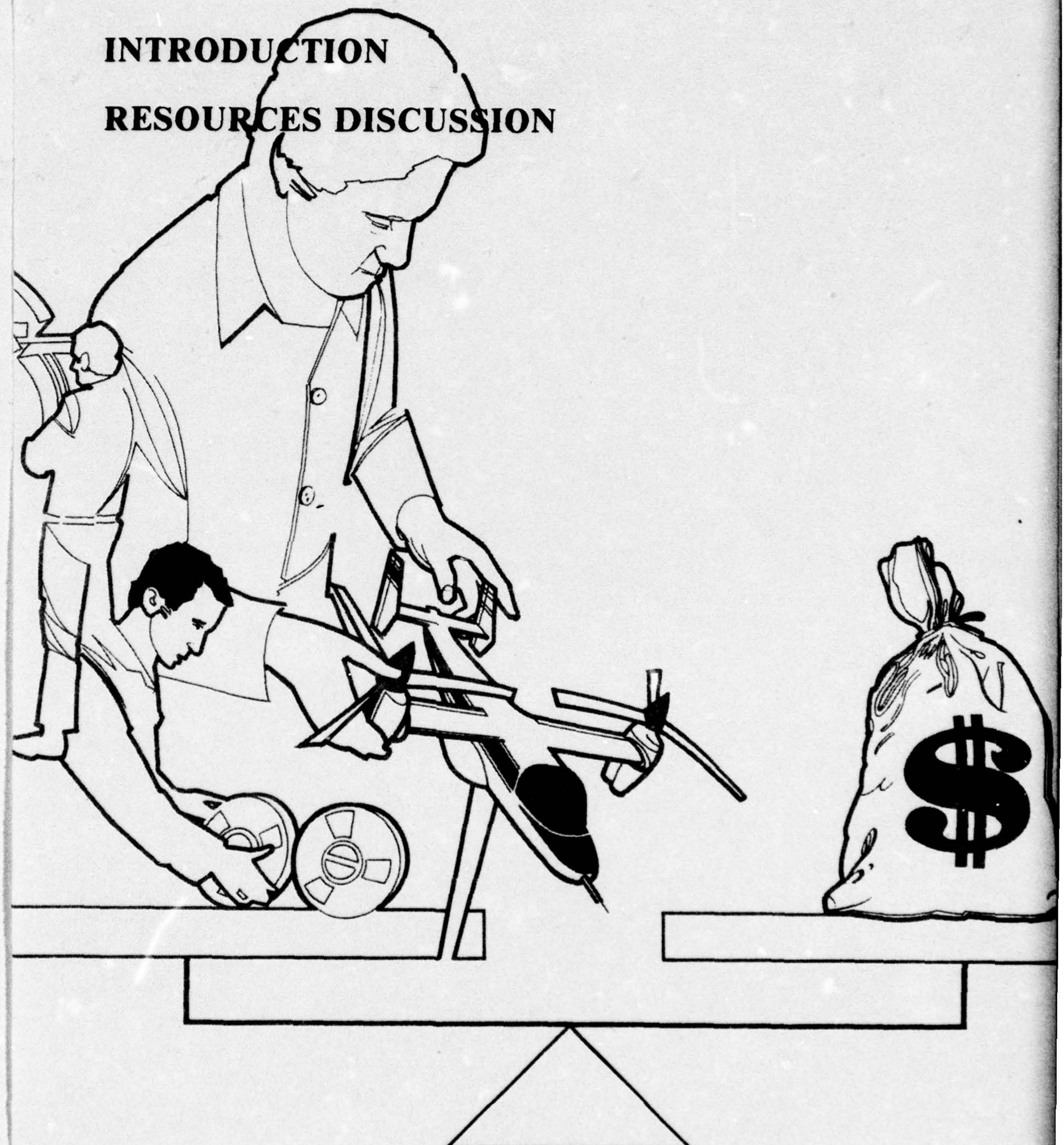
The concept of developing a test system that would allow both performance and acoustic experimental measurements to be made simultaneously has been evaluated by small scale experiments. The hover performance/acoustic test chamber and the rotor drive system, with a six-component balance, have been completed. Rotor strobed laser velocimeters have been tested and the laser anemometry equipment has been upgraded. The first wind tunnel tests

have proven the laser technique has the capability to measure the vortex velocity components immediately ahead and behind the rotor blade.

During FY77 the laser velocimeter equipment will be upgraded and tests will be made to determine the effect of blade passage on the trailing vortex from a preceding blade passage, the effect of vortex passage on the blade and the effects of blade-vortex interaction on near field radiated noise. This experimental data will provide a valuable design guide for the rotary wing manufacturing industry.

INTRODUCTION

RESOURCES DISCUSSION



INTRODUCTION

The Army Aviation RDT&E Plan presents a time-phased analysis of the scientific and technological programs required to support the development of advanced airmobile systems. A plan becomes a program only when the required resources in terms of funds, facilities, and personnel are provided for its implementation.

This section estimates the total resources, in terms of funds and personnel, needed to advance the state-of-the-art of the technologies and to develop airmobile materiel and systems. The estimates are primarily AVSCOM resources. Manpower requirements are based on professional and technical personnel, excluding clerical-type personnel. These estimates constitute a very large requirement, as they represent the commitments desired to achieve all of the technological objectives described in the preceding sections of this Plan. Included in the estimates are the resources needed for the development of aircraft systems that are project managed. Funds for aircraft weaponization programs are controlled by AVSCOM/AMRDL, though the work is primarily accomplished by ARMCOM, MICOM, and BRL. Aviation electronics resources are directly controlled by ECOM, although programs pertaining to airmobile systems are formally coordinated with AVSCOM. The aviation electronics resources are not reflected in the resource charts presented in this section.

Even if unlimited resources were available, it is not likely that all the efforts would be pursued and all the goals achieved. Therefore, an estimate of resource requirements that was based on developing all of the concepts of each of the projected systems would be unrealistic. Moreover, the available options and alternatives to perform a given task diminish rapidly with time, so estimates of resource requirements are valid only on a relatively short-term basis.

Even more to the point, however, is the fact that there are never enough resources to undertake all of the research projects that optimum planning would indicate. There are generally many more feasible technical alternatives available to solve a particular problem than can be economically supported. The problem is to decide which efforts are to be supported and which goals can be achieved under the conditions of limited resources. Compromises must be made among the myriad alternatives to maximize return on the investment. The stakes are too high to entrust the allocation of resources to top-of-the-head or arbitrary decisions. As a consequence of the broad scope and the complexity of this Plan, many factors must be considered to reach an effective decision. One decision can affect the operation of many efforts. Numerous efforts are interrelated; therefore, choices must be made with regard to the total effect considering the resources required, the objectives of each effort, and the impact of technological interchange between efforts. Recognizing the need for a rational, systematic resource allocation scheme, AMRDL has developed a Laboratory Project Selection Process to assist Laboratory Management in program/resource allocation (see Technology Introduction section).

RESOURCES DISCUSSION

For reference purposes, figure RR–1 is a summary of funds per current command schedule in terms of funding categories and PM requirements. It is noted that project managed funds are excluded from the 6.3 and 6.4 funding categories and are included in the PM category, even though they are 6.3 and 6.4 type of funds. The PM category consists of UTTAS, AAH, RPV, ASE, ASH, and PIP which includes the CH-47 and Cobra. The 6.4 funds in the figure may seem disproportionately small, but one must understand that the majority of AVSCOM 6.4 funds are project managed. Therefore, the 6.4 funds shown represent mainly developments of aircraft weaponization, cargo handling equipment, and ground support equipment.

Figures RR–2, 3, 4, and 5 show resources required by AVSCOM and PMs to implement the technological objectives and to develop future systems. Resources are exhibited in terms of funds and AVSCOM/PM manpower requirements. Only professional manpower requirements are shown. A major portion of the total resources for Advanced Technology Demonstration shown in figures RR–3 and RR–5 includes tilt rotor research aircraft, RSRA and ABC.

Figure RR–4 shows minimal manpower in the 6.4 category, as the majority of 6.4 manpower is in PM support rather than technology development work.

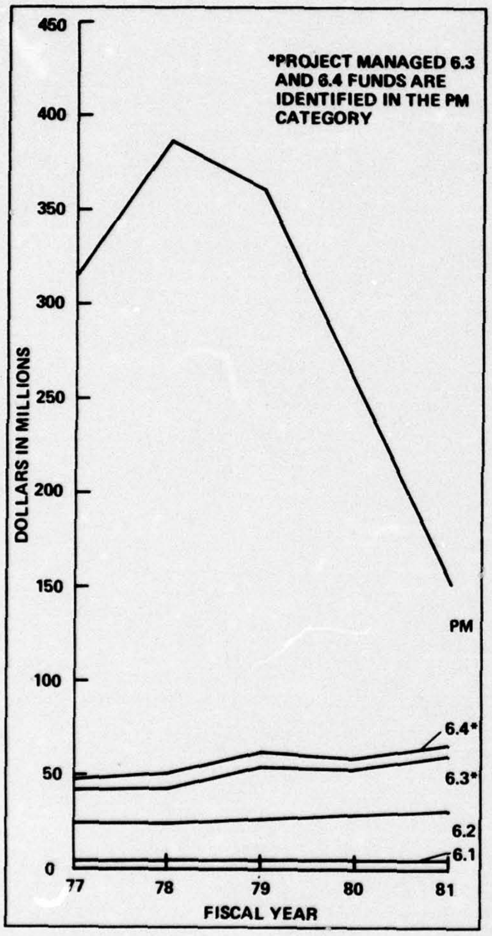


Figure RR–1. Distributions of funds by funding category and PM requirements.

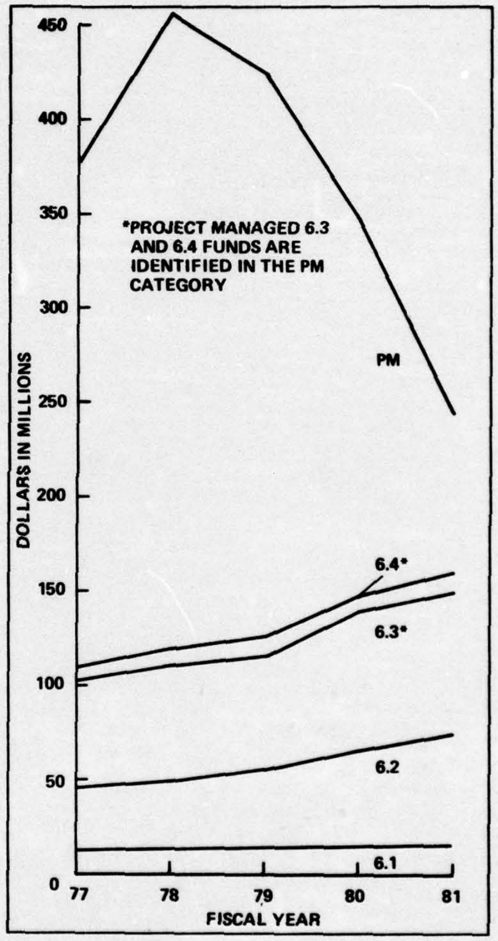


Figure RR–2. Distribution of required funds by funding category and PM systems.

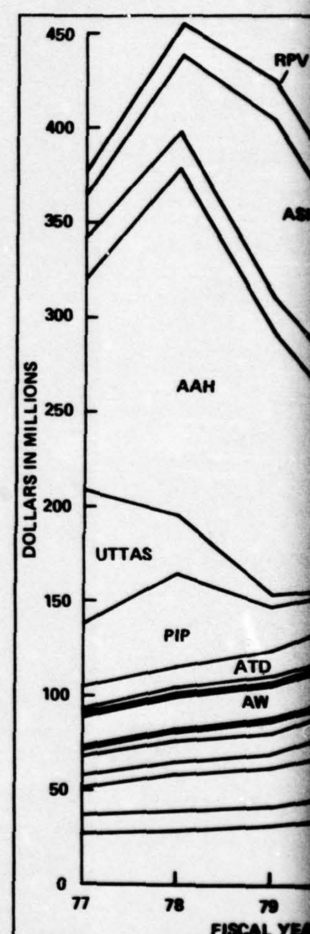


Figure RR–3. Distribution of
technology and PM

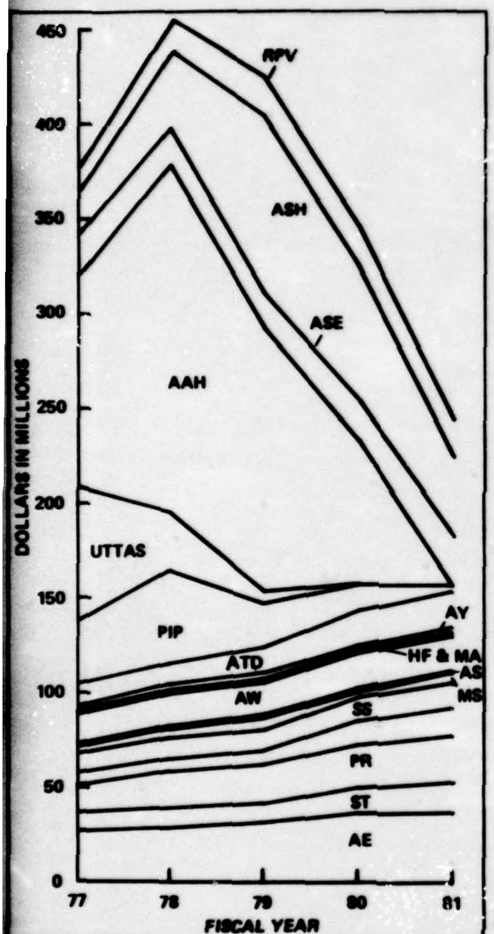


Figure RR–3. Distribution of required funds by technology and PM systems.

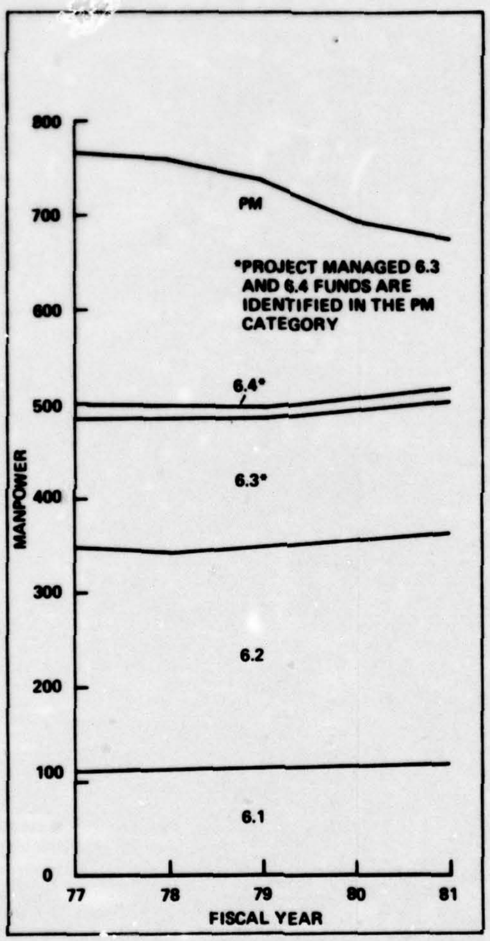


Figure RR–4. Distribution of required manpower by funding category and PM systems.

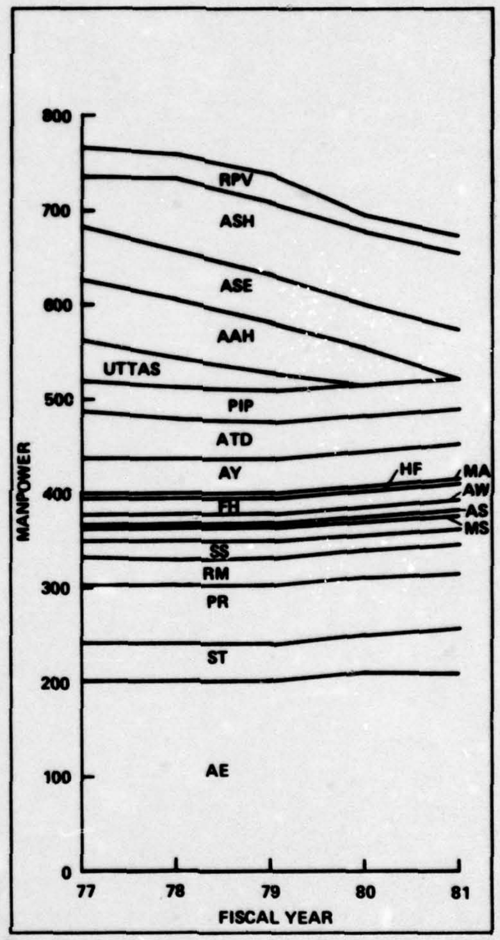
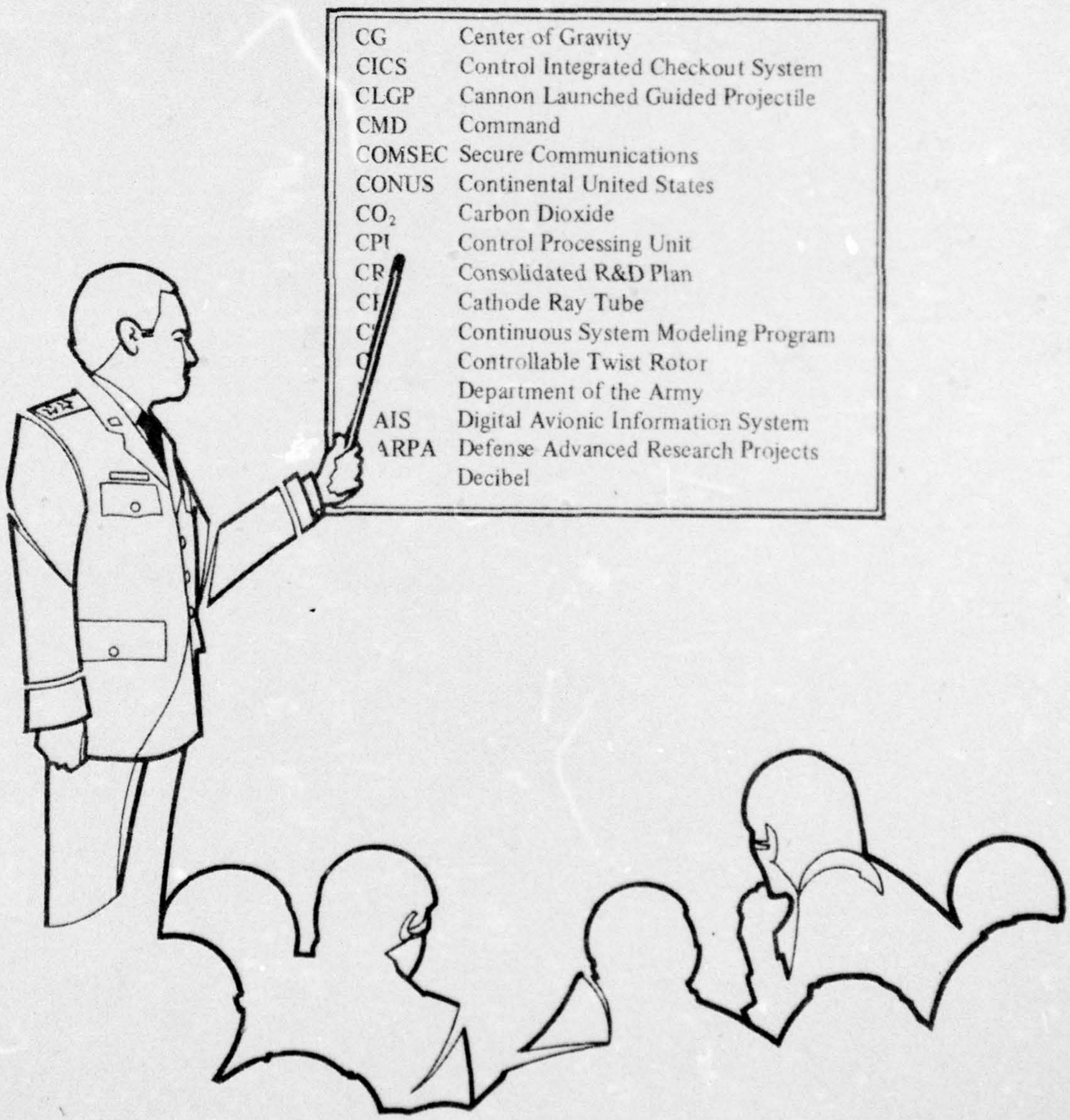


Figure RR–5. Distribution of required manpower by technology and PM offices.

BIBLIOGRAPHY

ABBREVIATIONS / ACRONYMS



BIBLIOGRAPHY

1. Air Mobility in the Mid/High Intensity Environment (AM/HI) (U), U.S. Army Combat Developments Command Institute of Special Studies, 1970–1971 (SECRET).

Volume	Major Item
I	AM/HI Study – Main Report (U) (SECRET) ANNEX A – Bibliography (U) (SECRET)
II	ANNEX B – Threat (U) (SECRET)
V	ANNEX E – Phase I Vulnerability to the Effects of Nuclear Weapons (U) (SECRET)
VI	ANNEX F – Phase I Survivability Analysis (U) (CONFIDENTIAL) ANNEX G – Feasibility of Air-to-Air Survivability Study (U) (CONFIDENTIAL)
VII	ANNEX H – Phase II, Modeling for Inclusion in Armored Cavalry Squadron Mix War Game (U) (CONFIDENTIAL)
IX	ANNEX I – Phase IIA, Air Cavalry Troop Helicopter Mix War Game (U) (CONFIDENTIAL)
X	APPENDIX 1 – Detailed Report (U) (CONFIDENTIAL)
XI	ANNEX J – Phase III Airmobility Feasibility War Game Summary Report (U) (SECRET)
XII	APPENDIX 1 – Phase III Airmobility Feasibility War Game – Game Narratives (U) (SECRET)
XIV	APPENDIX 5 – Narrative Summary and Description, Division Equivalent Force, European force Design, In Three War Game Situations (U) (SECRET)
XVI	Addendum Judgemental Evaluation of TRICAP and ACCB (U) (CONFIDENTIAL)

2. Catalog of Approval Requirements Document (CARDS), July 1973 (SECRET).

3. Research, Development and Engineering Five-Year Program, FY 1973–1977 (U), June 1972, AMC (SECRET).

4. Five-Year Implementing Plan, FY 1973–1977 (U), United States Army Aviation Systems Command, June 1971 (SECRET).

5. Advanced Attack Helicopter (AAH) Materiel Need (Engineering Development) (MN(ED)) (U), U.S. Army Combat Developments Command, 16 October 1972 (CONFIDENTIAL).

6. Required Operational Capability (ROC) Advanced Scout Helicopter (ASH) (U), U.S. Army Training and Doctrine Command, February 1974 (CONFIDENTIAL).

7. Utility Tactical Transport Aircraft System (UTTAS) Materiel Need (Engineering Development) (MN(ED)) (U), U.S. Army Combat Developments Command, 11 February 1972 (CONFIDENTIAL).

8. UTTAS System Development Plan (SDP (U) Project Manager, Utility Aircraft, USAMC, 29 March 1972 (CONFIDENTIAL).

9. Heavy Lift Helicopter (HLH) Advanced Development Plan (ADP) (U) Project Manager, Heavy Lift Transport Aviation Systems, USAMC, 25 February 1972 (CONFIDENTIAL).

10. Current Analysis of the Threat, Heavy Lift Transport Aviation System (U) U.S. AAVSCOM and FSTC, 19 October 1972 (SECRET).

11. Current Summary of the Threat – U.S. Army Aircraft, Timeframe 1974–1985 (U) USAAVSCOM, 2 August 1974 (SECRET).

12. Army Long Range Technical Forecast (ALRTF), U.S. Army Materiel Command, Advanced Materiel Concepts Agency, 1973 (SECRET).

13. Land Combat Systems Study–1 (LCS–1) (U) May 1972 (SECRET).

14. Five-Year Defense Program (U), Office of the Secretary of Defense (SECRET).

15. Science and Technology Objective Guide (STOG-77) (U), Dept. of the Army (CONFIDENTIAL).

16. Research and Technology Plan, FY76–FY80, Air Force Flight Dynamics Laboratory (FOUO).

17. FY75 Research Plan, Aerospace Research Laboratories, Air Force Systems Command (FOUO).

18. FM 1-1 Terrain Flying, Dept. of the Army (U).

19. FM 90-1 Employment of Army Aviation Units in a High Threat Environment, Dept. of the Army (U).

ABBREVIATIONS AND ACRONYMS

AA	Anti-aircraft
AACB	Aeronautics and Astronautics Coordinating Board
AAELSS	Active Arm External Load Stabilization System
AAH	Advanced Attack Helicopter
AAWS	Advanced Aerial Weapons System
ABC	Advancing Blade Concept
AC or ac	Alternating Current
A/C	Aircraft
ACT	Automatic Canon Technology
ADEN/DEFA	British/French 30mm Aircraft Cannon
ADF	Automatic Direction Finding
ADO	Advanced Development Objective
ADS	Aeronautical Design Standards
AEFA	Aviation Engineering Flight Activity
A&FC	Airworthiness and Flight Characteristics
AFAMM	Aerial Field Artillery, Multi-Mode
AFB	Air Force Base
AFCS	Automatic Flight Control System
AFDP	Army Force Development Plan

AGARD	Advisory Group for Aerospace Research and Development
AGL	Above Ground Level
AHT	Attack Helicopter Team
AIDAPS	Automatic Inspection Diagnostic and Prognostic System
AIDATS	Army In-Flight Data Transmission System
AISI	American Iron and Steel Institute
ALT	Airborne Laser Tracker
AM	Amplitude Modulation
AMC	Army Materiel Command (now DARCOM)
AMCAWS	Advanced Medium Caliber Aircraft Weapon System
AMMRC	Army Materials and Mechanics Research Center
AMP	Amphere
AMPC	AMC Pamphlet
AMRDL	Air Mobility Research and Development Laboratory
AP	Armor-Piercing
APE or APEval	Army Preliminary Evaluation
API	Armor-Piercing Incendiary
APPS	Analytical Photogrammetrical Position System
APU	Auxiliary Power Unit
AQP	Airworthiness Qualification Program
AQS	Airworthiness Qualification Specification
AR	Army Regulation
ARDPS	Army R&D Planning System
ARL	Aeromedical Research Laboratory
ARMCOM	(U.S. Army) Armament Command
ARMS	Aircraft Reliability and Maintainability Simulation
ARO	Army Research Office
ARPA	Advanced Research Project Agency
ARS	Aircraft Rocket Subsystem
ASARC	Army Systems Acquisition Review Council
ASCOD	Army System Coordinating Documents
ASE	Aircraft Survivability Equipment
ASH	Advanced Scout Helicopter
ASOP	Army Strategic Objectives Plan
ASRO	Advanced Systems Research Office
ASTD	Advanced Structures Technology Demonstrator
AT/AV	Anti-tank/Anti-vehicle
ATAFCS	Airborne Target Acquisition and Fire Control System
ATC	Advanced Technology Components or Air Traffic Control
ATDE	Advanced Technology Demonstrator Engine
ATE	Advanced Technology Engine
ATEGG	Advanced Technology Engine Gas Generator
ATMS	Air Traffic Management System
AVIM	Aviation Intermediate Support Maintenance
AVSCOM	(U.S. Army) Aviation Systems Command
AVUM	Aviation Unit Maintenance
AWLS	Airborne Weapons Locating System
BED	Basic Engineering Development
BRL	Ballistics Research Laboratory

CAD	Computer-Aided Design
CAD-E	Computer-Aided Design and Engineering
CAM	Computer-Aided Manufacturing
CARDS	Catalog of Approved Requirements Document
CBR	California Bearing Ratio
CCD/CID	Charge Coupled Device/Charge Injected Device
CDC	Combat Development Command or Control Data Corporation
CDEC	Combat Developments and Experimentation Command
CDR	Critical Design Review
CDS	Cleaning and De-icing System
CDU	Control Display Unit
CEP	Circular Error Probable
CG	Center of Gravity
CICS	Control Integrated Checkout System
CIP	Component Improvement Program
CLGP	Cannon Launched Guided Projectile
CMD	Command
COMSEC	Secure Communications
CONUS	Continental United States
CO_2	Carbon Dioxide
CPU	Control Processing Unit
CRDP	Consolidated R&D Plan
CRT	Cathode Ray Tube
CSTA	Combat Surveillance and Target Acquisition Laboratory
CTOL	Conventional Takeoff and Landing
CTR	Controllable Twist Rotor
CWS	Collision Warning System
DA	Department of the Army
DARCOM	(U.S. Army) Materiel Development and Readiness Command
DARPA	Defense Advanced Research Projects Agency
dB	Decibel
DC or dc	Direct Current
DEPSECDEF	Deputy Secretary of Defense
D&F	Determination & Finding
DGW	Design Gross Weight
DIMAP	Digital Modular Avionics Program
DIMODE	Discontinuity Modulation Effect
DME	Distance Measuring Equipment
DN	Diameter (mm) Times RPM
DOC	Direct Operating Cost
DP	Development Plan
DPS	Dynamic-Propulsion System
DPROC	Draft Preliminary ROC
DS	Direct Support (now Intermediate Support Level)
DSARC	Defense Systems Acquisition Review Council
DOD	Department of Defense
DOT	Department of Transportation
DT	Development Test
DTB	Detection Time Variation

ECCM	Electronic Counter Countermeasures
ECM	Electronic Countermeasures or Electrochemical Machining
ECOM	(U.S. Army) Electronics Command
EDM	Electrical Discharge Machining
EDT	Engineering Development Test
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
ERP	Effective Radiating Power
ET	Engineering Test
EW	Electronic Warfare
EWL	Electronic Warfare Laboratory
F	Fahrenheit
FAA	Federal Aviation Administration
FARRP	Forward Area Rearm/Refuel Point
FBW	Fly-by-wire
FCC	Flight Coordination Center
FDS	Flight Director System
FEBA	Forward Edge of Battle Area
FFAR	Folding Fin Aerial Rocket
FFH	Fast Frequency Hopping
FLIR	Forward Looking Infrared
FM	Frequency Modulation
FOC	Flight Operations Center
FOD	Foreign Object Damage
FORSCOM	(U.S. Army) Forces Command
FORTRAN	Formula Translation
FPM	Feet Per Minute
FT or ft	Feet
FY	Fiscal Year
FYDP	Five Year Defense Plan
G or g	Gravity
GCA	Ground Controlled Approach
GCS	Ground Control Station
GCT	Government Computation Test
GE	General Electric Company
GFP	Government Furnished Property
GHz	Gigahertz
GLAS	Gust and Load Alleviation System
GLLD	Ground Laser Locator Designator
GPM	Gallons Per Minute
GPS	Global Positioning System
GPSS-V	General Purpose System Simulator-V
GPU	Ground Power Unit
GS	General Support (now Intermediate Support Level)
GSE	Ground Support Equipment
GTV	Ground Test Vehicle

HE	High Explosive or Human Engineering
HEAT	High Explosive Anti-Tank
HEDP	High Explosive Dual Purpose
HEI	High Explosive Incendiary
HEL	Human Engineering Laboratory
HELLFIRE	Helicopter Launched Fire and Forget Antitank Missile System
HERF	High Energy Rate Forming
HF	High Frequency or Human Factors
HHLR	Handheld Laser Rangefinder
HLH	Heavy Lift Helicopter
HMD	Helmet Mounted Display
HMMS	HELLFIRE Modular Missile System
HOGE	Hover Out-of-ground Effect
HOT	High IR Subsonic Optically Guided
HP	Horsepower
HQ	Headquarters
HR or hr	Hour
HUD	Head-up Display
Hz	Hertz
I^2	Image Intensifiers
IACS	Integrated Avionics Control System
IBM	International Business Machines Corporation
ICAO	International Civil Aviation Organization
ICNI	Integrated Communication, Navigation, Identification
ICNS	Integrated Communication and Navigation System
IFF	Identification, Friend or Foe
IFR	Instrument Flight Rules
ILLIAC IV	Fourth Generation Computer with Sixty-Four Slave Processors Working on *Master/Slave Concept*
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IMLS	Interim Microwave Landing System
I/O	Input/Output
IOC	Initial Operational Capability
IPR	In Process Review
IR	Infrared
IRCM	Infrared Countermeasures
IR&D	Independent Research and Development
ISM	Intermediate Support Maintenance
ISO	International Standards Organization
JCS	Joint Chiefs of Staff
JCTG	Joint Commander's Technical Group
KN or kn	Knots
KE	Kinetic Energy
KM or km	Kilometer
KVA or KW	Kilowatt
KTAS	Knots-True Air Speed

LA	Low Altitude
LAH	Light Attack Helicopter
LARS	Laser Aided Rocket System
LB or lb	Pound
LCC	Life Cycle Cost
LCMM	Life Cycle Management Model
L/D	Lift/Drag
LINS	Laser Inertial Navigation System
LLLTV or LLTV	Low-Light-Level TV
LLNO	Low Level Night Operations
LOA	Letter of Agreement
LOH	Light Observation Helicopter
LORAN	Long-Range Navigation
LOS	Line-of-Sight
LOTAWS	Laser Obstacle/Terrain Avoidance Warning System
LOTS	Logistics Over-The-Shore
LP	Limited Production
L&R	Launch and Recovery
LRIP	Limited Rate-Initial Production
LSI	Large Scale Integration
LUH	Light Utility Helicopter
LWLD	Lightweight Laser Designator
LZ	Landing Zone
MAD	Multifunction Aviation Display
MASSTER	Modern Army Selective System Test, Evaluation and Review (now TRADOC Combined Arms Test Activity)
MARS	Mid-Air Recovery System
MAT	Maturity
MBO	Mean Time Between Overhaul
MERADCOM	(U.S. Army) Mobility Equipment Research and Development Command
MHD	Magnetohydrodynamics
MICOM	(U.S. Army) Missile Command
MLH	Medium Lift Helicopter
MLS	Microwave Landing System
MM or mm	Millimeter
MMAS	Mini-Manned Aircraft System
MMH/FH	Maintenance Manhours per Flight Hour
MMT	Manufacturing Methods and Technology
MN	Materiel Need
MQT	Material Qualification Test
MRP	Military Rated Power
MSL	Mean Sea Level
MT	Manufacturing Technology
MTBF	Mean Time Between Failures
MTBR	Mean Time Between Removal
MTBUM	Mean Time Between Unscheduled Maintenance
MTI	Moving Target Indicator or Mechanical Technology
MTTR	Mean Time to Repair
MWFCS	Multi-Weapon Fire Control System
μm	Micron

NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structure Analysis
NATO	North Atlantic Treaty Organization
NC/CAM	Numerical Control/Computer-Aided Manufacturing
NM	Nautical Mile
NMLS	National Microwave Landing System
NOE	Nap of the Earth
NRP	Normal Rated Power
NVL	Night Vision Laboratory
OCRD	Office, Chief of Research and Development
OCS	Optical Contrast Seeker
ODDR&E	Office of the Directorate of Defense Research and Engineering
OGE	Out of Ground Effect
O&O	Organizational And Operational
OPR	Objectives, Priority and Rationale
OPTIC	OTAS (Observer Target Acquisition System)
	PNVS (Pilot Night Vision System)
	Tactically
	Integrated
	Cobra
OSD	Office, Secretary of Defense
OT	Operational Test
OTAS	Observation Target Acquisition System
PADS	Piloted Aircraft Data Systems
PANS	Position and Navigation System
PDR	Preliminary Design Review
PEM	Production Engineering Measures
PEMA	Procurement of Equipment and Missiles, Army
PEP	Producibility Engineering and Planning
PFAT	Preliminary Flight Approval Test
PIDD	Prime Item Description Document
PINE	Pilots Infrared Night Equipment
PIP	Product Improvement Program
PLRS	Position Location Reporting System
PM	Project Manager
PNVS	Pilot Night Vision System
POL	Petroleum, Oil and Lubricants
POM	Program Objectives and Memorandum
P/R	Pseudo-Random
PSDE	Preliminary Systems Design Engineering
PSF or psf	Pounds per Square Foot
PSG/MFD	Programmable Symbol Generator and Multifunction Display
PSI or psi	Pounds per Square Inch
PVP	Processor/Viewer/Printer
PWD	Proximity Warning Device
QMDO	Qualitative Materiel Development Objective
QMR	Qualitative Materiel Requirement

RAGS	Research Aircraft Ground Station
RAM	Reliability, Availability, and Maintainability
RAM/D	Reliability, Availability, Maintainability, Dependability
RAMP	Ring Anti-Material Projectile
RC	Radio Control
RCS	Radar Cross Section
R&D	Research and Development
RDE	Research, Development and Engineering
RDT&E	Research, Development, Test and Engineering
RF	Radio or Radar Frequency
RFP	Request for Proposal
R&M	Reliability and Maintainability
RMI/HSI	Radio Magnetic Indicator/Horizontal Situation Indicator
RMS or rms	Root Mean Square
ROC	Required Operational Capability
RPAODS	Remotely Piloted Aerial Observation/Designation System
RPM or rpm	Revolution Per Minute
RPV	Remotely Piloted Vehicle
RR	Resources Required
RSRA	Rotor Systems Research Aircraft
RSTA/D	Reconnaissance, Surveillance, Target Acquisition and Designation
RTCOD	Research and Technology Coordinating Document
RVR	Runway Visual Range
SAM	Surface to Air
SAS	Stability Augmentation System
SCAS	Stability and Control Augmentation System
SDR	Small Developments Requirements
SEANITEOPS	Southeast Asia Night Operations
SEAS	Selective Effects Armament Subsystem
SEC or sec	Second
SFC	Specific Fuel Consumption
SHP	Shaft Horsepower
SIF	Selectable Identification Feature
SINCGARS	Single Channel Ground and Airborne Radio System
SLAE	Standard Lightweight Avionics Equipment
SLAR	Side-Looking Airborne Radar
SLS	Sea-Level Standard
SNAPAC	Stearable Null Antenna Processor for Airborne Communications
SOFTAR	Stand-Off Fixed Target Detection Radar
SOTAS	Stand-Off Target Acquisition System
SRIO	Systems Research Integration Office
SSB	Single Sideband
ST	Service Test
STA	Static Test Article
STD	System Technology Demonstrator
STAGG	Small Turbine Advanced Gas Generator
STOG-77	Science and Technology Objective Guide, FY77 (CONFIDENTIAL)
STOL	Short Takeoff and Landing
SUR/VTOL	Surveillance/Vertical Takeoff and Landing Aircraft System

TACAN	Tactical Air Navigation
TACFIRE	Tactical Fire Direction System
TAGS	Tactical Aircraft Guidance System
TAMMS	The Army Maintenance Management System
TA/TF	Terrain Avoidance/Terrain Following
TBO	Time Between Overhaul
TBR	Time Between Removal
TCP	Technical Coordinating Papers
TDMA	Time Digital Multiple Access
TLL	Tactical Low-Level
TLS	Tactical Landing System
TOW	Tube Launched, Optically Tracked, Wire Guided
TRADOC	(U.S. Army) Training and Doctrine Command
TROSCOM	(U.S. Army) Troop Support Command
TTCP	The Technical Cooperation Panel
TV	Television
UA	Up and Away
UACL	United Aircraft of Canada, Limited
UFIR	Universal Far Infrared
UHF	Ultra High Frequency
USAAEFA	U.S. Army Aviation Engineering Flight Activity
USAAMRDL	U.S. Army Air Mobility Research and Development Laboratory
USAARL	U.S. Army Aeromedical Research Laboratory
USAARMCOM	U.S. Army Armament Command
USAAVSCOM	U.S. Army Aviation System Command
USACDC	U.S. Army Combat Developments Command
USACDEC	U.S. Army Combat Developments and Experimentation Command
USADARCOM	U.S. Army Materiel Development and Readiness Command
UASECOM	U.S. Army Electronics Command
USAF	U.S. Air Force
USAFORSCOM	U.S. Army Forces Command
USAMERADCOM	U.S. Army Mobility Equipment Research and Development Command
USAMICOM	U.S. Army Missile Command
USAMMRC	U.S. Army Materials and Mechanics Research Center
USAREUR	U.S. Army, Europe
USATRADOC	U.S. Army Training and Doctrine Command
USATROSCOM	U.S. Army Troop Support Command
USMC	U.S. Marine Corps
USN	U.S. Navy
UTM	Universal Transverse Mercator
UTS	Ultimate Tensile Strength
UTTAS	Utility Tactical Transport Aircraft System
V	Vertical or Air Speed
VE	Value Engineering
VHF	Very High Frequency
VHLH	Very Heavy Lift Helicopter
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range

VR	Vulnerability Reduction
VROC	Vertical Rate of Climb
V/STOLAND	V/STOL Advanced Autopilot System
VTOL	Vertical Takeoff and Landing
WSM (O)	Weapons Systems Manger (Office)
WOWS	Wire Obstacle Warning System
WP	White Phosphorous
WT or wt	Weight